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(Vol. XVI., March, 1887.)

THE EFFECT OF FREEZING ON CEMENT-MORTAR.

By ALFRED NOBLE, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JULY 5TH, 1886.

WITH DISCUSSION.

In the construction of a lock at the St. Mary's Falls Canal, the laying of masonry was discontinued about October 20th of each year on account of the frequent recurrence of freezing weather. On the last day of the work in 1877, mortars of Portland cement and of a good quality of American natural cement were used in adjoining portions of the wall. The same proportions of cement and sand, 1 to 1, were used in both classes of mortar. This masonry was laid during a light rain. The following spring the surface of the Portland cement-mortar was sound, showing perfectly the marks of the rain drops. The natural cement-mortar was disintegrated to a depth of 3 or 4 inches.

In the same locality it was necessary to lay a concrete foundation for a movable dam in February. The weather was extremely cold, generally about zero. The mortar was made with Portland cement. Salt was used freely, but without retarding very much the freezing of the concrete. The concrete was at once covered with a floor of timber and plank on which the masonry abutments were built. Samples of the frozen mortar set properly after being put in a warm place. There was never any settlement of the masonry, and within a few months the concrete sustained a pressure of 15 feet of water without developing any leaks.

In the construction of a bridge across the Clark's Fork of the Columbia River in Northwestern Montana, the caissons were filled with concrete during freezing weather. Portland cement was used. The proportions of cement to sand were 1 to 3. Within a week the laying of stone masonry was commenced on these caissons, and proceeded with as rapidly as possible without apparent injury to the concrete, which had set firmly. In these cases the temperature had risen above the freezing point within two or three days after the concrete had been placed; and it had been permeated to some extent by warm air escaping through leaks from the air-chamber.

Four small piers were built for the St. Louis River Bridge on the Northern Pacific Railroad, near Duluth, in the winter of 1884–85. During the laying of masonry for pier 1, the temperature varied from 0 to 20 degrees; during the building of pier 2, the temperature was about 20 degrees higher, and during the building of the remaining piers the temperature was occasionally above the freezing point. Portland cement was used throughout, the proportions of cement and sand being 1 to 1½ for face stone, and 1 to 2½ for backing. During the extremely cold weather salt was used freely in the mortar and the sand was warmed (not made hot), but with the thermometer at 20 degrees the mortar froze quickly after being spread on the stone; so quickly, indeed, that if the stone, being set, could not be brought to a bearing by a little shaking, it was necessary to raise the stone, scrape off the now frozen mortar, and spread a new bed. In setting the face-stone the mortar was kept back from the face an inch or so to facilitate subsequent pointing. A few weeks later, after there had been milder weather, an examination of the open edges of the mortar beds showed that the mortar used during the coldest weather had set firmly, and no difference could be detected by examination of detached fragments between the mortars in piers 1 and 4; that is to say, between that laid in the coldest and that laid in the mildest weather embraced in the period of construction of these piers.

During the course of tests of cement at the St. Mary's Falls Canal, a few experiments were made relating to the effect of freezing and the use of salt on cement-mortars. They are not submitted as conclusive in any way, but as suggestive, and in the hope that, combined with others, some definite conclusion may be reached.

TABLE A.

EFFECT OF FREEZING ON MORTARS OF PORTLAND CEMENT CONTAINING VARYING AMOUNTS OF SALT.

Composition of Mortar.

Cement..... 35 ounces.
Water..... 7 "

Salt as in table.

Tensile strength per square inch at seven days.

TREATMENT.	SALT.								
	0.	½ oz.	¼ oz.	⅜ oz.	½ oz.	⅝ oz.	¾ oz.	⅞ oz.	1 oz.
FIRST SERIES.									
Immersed in test-room when removed from moulds.....	327	357	375	392	429	402	415	388	402
Exposed to air when removed from moulds and frozen three days; then immersed in test-room four days.....	316	378	411	374	415	405	392	383	409
SECOND SERIES.									
Immersed in test-room when removed from moulds.....	336	422	421	399	394	384	390	356	387
Exposed to air when removed from moulds and frozen six days; then exposed to air in test-room at 70 degrees one day.....	169	198	167	217	227	215	208	221	239

TABLE B.

EFFECT OF MIXING SALT WITH PORTLAND CEMENT-MORTAR.

Proportions by measure.

Cement..... 1.
Sand..... 1.

Proportions by weight.

Cement..... 21 ounces.
Sand..... 23 "
Water..... 6 "

Salt as in table.

Means of ten tests.

SALT.	TENSILE STRENGTH, POUNDS PER SQUARE INCH.							
	7 days.	30 days.	90 days.	6 mos.	9 mos.	12 mos.	18 mos.	24 mos.
0.....	155	220	289	311	390	382	402	430
¼ ounce.....	139	200	246	288	363	364	423	346
½ "	139	192	221	289	352	383	392	326
1 "	128	189	217	288	343	369	350	334

DISCUSSION.

F. Collingwood, M. Am. Soc. C. E.—Mr. Noble said that he found the natural cements did not stand the cold as well as the artificial cements; that he always found the natural cements to be damaged two or three or four inches from the face of the joints after they had been exposed to very severe freezing, and we found something of the same kind in our work on the East River Bridge. On any wide wall where water could collect on top and where it was exposed to the weather all through the winter, we found that we would have to scrape out the joints, but the face joints never troubled us. We used the Rosendale cements.

George S. Morison, M. Am. Soc. C. E.—As bearing immediately upon the subject of freezing, I might mention an accidental experiment that occurred last winter in the work on the Omaha Bridge. I had quite a number of briquettes made of American cements and imported Portland cements, which were exposed to the air twenty-four hours and then left in the customary way in a pail of water. There came on extremely cold weather, and the entire lot became a solid block of ice. When it thawed out the Portland cements were entirely uninjured, but the American cements were entirely ruined, some of them being reduced to mud. Subsequent experiments showed that the cements which stood freezing three days after they were made, would also stand freezing immediately after they were mixed. It has been for some years my practice to use Portland cement exclusively in places where the mortar was likely to freeze before setting.

Robert B. Stanton, M. Am. Soc. C. E.—I have had some experience in laying masonry in very cold weather. In the winter of 1878 and 1879 it was found that a small pier on the Cincinnati Southern Railway was defective. The pier was taken down and rebuilt with Louisville cement, and with the use of salt. The thermometer at the time ranged from 6 to 10 degrees below zero. The iron trestle was put upon the pier, and during the winter no change in the masonry was noticed. When, during the next summer, it became very hot, the pier seemed to sweat; the salt came out and made the sides white, but the cement was as hard as if it had been laid in the summer, and, so far as I have since learned, there has never been any trouble with that pier.

In the winter of 1881, here in Denver, in building the round house and shops of the Union Pacific yards it became cold very suddenly. After waiting for awhile, the weather not getting more moderate, the work was proceeded with and salt was used in lime-mortar, and every night the top was covered with a thick coat of salt; the mortar was not really frozen. The next summer a locomotive got away and struck this masonry between the two windows, tearing away the lower portion and leaving the whole keystone portion above suspended and held up by the mortar, and this masonry hung thus for several weeks: It is possible that the mortar did not freeze during the day, but during the night the temperature was very low.

ELIOT C. CLARKE, M. Am. Soc. C. E.—Some years ago I made a number of experimental batches of concrete, some of Rosendale cement and some of Portland cement. Of these a portion were made with a large proportion of cement, and some weaker, of each kind. I made them just before freezing weather and left them out, being engaged on work in which some concrete had to be exposed in that way.

They were left for two or three years exposed, and during the first winter the Rosendale concretes without exception began to weather badly on the surface, and from year to year disintegrated; none of the Portland cement concretes were affected at all in three years, though lying right on the surface of the ground in blocks about a foot square.

I remember once talking with Mr. Shanahan, who is the Superintendent of Public Works of the State of New York, about his practice on the Erie Canal, and he told me that he would as willingly build masonry in the winter as in the summer, so far as its durability was concerned. He used Rosendale cement in building masonry, a tolerably strong mortar; that is a large proportion of cement to the sand; and always used in mixing only the strongest brine; that is, water saturated with salt, so that it would foam on top. He said he never knew a case to fail built in that way.

JOHN BOGART, M. Am. Soc. C. E.—I have had occasion to examine recently the masonry referred to by Mr. Clarke, built upon the line of the Erie Canal. This masonry was the retaining wall of the West Shore Railroad where it runs along the canal; where it was first laid in very cold weather, without the proper use of salt, it gave way and got into very bad condition. Directions were then given and carried out, for using a strong solution of salt for mixing the mortar, one barrel of brine

being mixed when another was being used for mortar. The result has been very satisfactory, and the masonry is in excellent condition.

J. JAMES R. CROES, M. Am. Soc. C. E., replying to a question as to the use of salt, quoted from a paper presented by him in 1874 on the construction of a masonry dam: "In freezing weather the mortar was mixed with salt water. The rule for proportion of salt was one said to have been used in the works at Woolwich Arsenal some years ago, viz.: Dissolve one pound of rock salt in eighteen gallons of water when the temperature is at 32 degrees Fahr., and add three ounces of salt for every 3 degrees of lower temperature. The masonry laid with mortar thus prepared stood well, and showed no signs of having been affected by the frost."

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IRRIGATION.

By EDWARD BATES DORSEY, M. Am. Soc. C. E.

READ NOVEMBER 17TH, 1886.

WITH DISCUSSION.

One of the first surveys with which the writer was connected was for the purpose of irrigating an extensive district in Northern Peru. During the three years of this survey, he studied, practically, irrigation as practiced there. Since then he has been a close observer of it as practiced throughout South America, Mexico, Colorado, Utah, California and Italy. As his knowledge of it has increased, so has his faith in its great advantage and importance. It could be introduced profitably in most places and in most climates. Perhaps some few meadow and bottom lands would not be improved by it. On the other hand, one frequently sees irrigated meadows in England, notwithstanding its damp climate and frequent rains.

In no part of the world has so much money, talent or attention been given to irrigation as in Italy, yet the climate there is very much the same as Eastern New York, the annual average rainfall being about 39 inches, with about four inches per month in April, May, June and July, the months the crops are growing and maturing. Notwithstanding this heavy rainfall, there has been expended about $200 per acre to bring and distribute the water in some districts.

In India, where the English government has spent so much money

in irrigation works—up to 1881, $86 000 000—the annual rainfall is, except in a few small districts, as large as it is here. For example, in the districts irrigated by the Ganges and Jumna Canals it is 38 inches.

In Italy, France and most of India, the rainfall is ample for ordinary crops; irrigation is adopted to increase the yield and to prevent the failure of crops by drought. These reasons will apply equally as well to all other countries; the general impression that irrigation is only necessary or useful in dry countries is entirely incorrect.

One can see at our own door, at the present time, the advantages on plant life of irrigation in this climate—which 55 000 000 of our people have been taught does not require it—the rains being considered all-sufficient. The grass plot in front of this house for some reason had not been watered, and the grass is far from being in a thrifty condition, while other plots on the opposite side of the street have been irrigated, their owners not trusting entirely to Providence. The difference between these adjacent plots is about as great as that between an irrigated Colorado farm and the cattle ranch on the adjoining unirrigated land.

The same can be seen in any village or town. The house that has plenty of water has always green grass and thriving flowers, while in those who do not have abundance of it, the opposite is the case. If water is so necessary to make grass grow for ornament, it is just as necessary to make it grow for hay and pasturage. Commercial vegetation is governed by the same law as ornamental. With a complete system of irrigation, any necessary quantity of water can be placed whenever or wherever desired, thus assuring the largest yield of crops, without the possibility of failure from drought, partial or complete. Many of our Eastern farmers know by sad experience that this frequently happens.

Arid Section of the United States.

Few persons have any idea of the importance of irrigation to the future prosperity of the United States. Heretofore there has been plenty of public land open to settlement at Government prices; now there is but little left that can be farmed profitably without irrigation.

The total area of the United States, excluding Alaska, is 3 547 000 square miles; of this 1 387 000 square miles, or more than one-third, cannot be farmed without irrigation, excepting a few bottoms and meadows comparatively of small extent.

Unless otherwise stated in speaking of the United States, the following remarks will apply to this desert or dry section only.

The annual average precipitation of moisture in the form of rain or snow over the valleys and plains of this section is about sixteen inches, increasing as the elevation of the mountains increase. This moisture is a great help to irrigation, but alone it is not sufficient for crops.

Duty of Water.

This is very variable, being influenced by the soil, climate, crops, price of water; whether the water is bought by so much for irrigating a crop or an acre, or by measurement; and last, but not least, by the intelligence of the irrigator.

The following table has been compiled from the most reliable available authorities, and is believed to be substantially correct.

TABLE No. 1.

Locality.	Crop.	Average Rainfall.		Duty.
		In irrigating or crop-growing months, March to September.	Per annum.	
		Inches.	Inches.	Areas.
Jumna Canal, India	Wheat, maize, etc	.....	38 to 44	306
Ganges " "	" "	.....	38 to 56	232
Upper India	" "	.....	.....	267
Northern "	Cereals	.....	38	200
Genil Canal, Spain	" and vines	6	22	240
Valencia, "	"	5	16	200
" "	Corn, grass, etc	5	16	324
" "	Garden and orchards	5	16	162
Northern Peru	Corn and cott n	0	00	160
" Chili	" grain	0	00	190
Lombardy, Italy	All crops, including rice	22	38	90
Piedmont, "	"	28	38	60
Average all "	"	25	38	67
United States.				
California, San Joaquin Valley	Cereals	2	10	200
Colorado, Denver	All crops	10	14	56
Utah, Camp Douglas	"	10	17	60 to 100
Idaho, Boise City		10	17	No reliable data.
Wyoming, Cheyenne		9	10	"
Arizona, Fort Mojave		2	5	"
Nevada, Winnemucca		3	6	"
Kansas, Dodge City		14	17	"
Montana, Fort Benton		10	13	"
Dakota, Fort Buford		12	17	"
Nebraska, North Platte		15	18	"
New Mexico, Santa Fé		10	14	"
Oregon, Umatilla		4	9	"

The duty of water is calculated upon the usual basis of the number of acres irrigated by one cubic foot of water per second. As before stated, this is a very variable quantity, differing in each locality. The amount put down is an average of what has been reported.

This table is very instructive. In Italy water is abundant and cheap; in fact irrigation is hardly necessary, as the rainfall would be considered sufficient in other countries; consequently the irrigators are very wasteful in applying the water, and it does only one-third the duty it performs in Spain, where it is scarce and dear, and absolutely necessary in farming, owing to the small rainfall. The preceding table shows that the rainfall of our arid section resembles very much that of Spain. Irrigation would probably accomplish the same beneficial results here as there.

In 1873, by Act of Congress, a commission was appointed to examine and report on a system of irrigation for California, This commission consisted of General B. S. Alexander and Colonel George H. Mendell, M. Am. Soc. C. E., United States Engineers, and Mr. George Davidson, United States Coast Survey. After thorough investigation of what was being accomplished in California, Europe and Asia, they reported that a duty of 200 acres per each cubic foot of water might be calculated upon in Central California, where the average annual rainfall is about ten inches.

Under the direction of the United States Government, Mr. George Davidson, of the United States Coast Survey, made a personal examination of irrigation as practiced in India, Egypt and Italy. His examination and report were made in his usual thorough style.

Of irrigation in India he says: "The works projected, and nearly all in progress, are estimated to cost $169 950 000. With their completion we may safely say that the population will be doubled; famines will be mitigated; the government revenue will certainly be more than doubled." He gives the following as the duty of water in India. One cubic foot per second irrigated

Wheat, maize, etc., in Upper India	.....	267 acres.
" on East Jumna Canal	.....	306 "
" Ganges "	.....	232 "

This means an average depth of 32, 28 and 37 inches respectively, exclusive of rainfall.

Login says: "In India, 10 inches of water, distributed in four water-

ings each of 2½ inches in depth, is sufficient for wheat and similar crops."

Mr. Davidson, in speaking of Central California (where the rainfall will average about ten inches annually), after reviewing what he had seen in India, Egypt and Italy, sums up as follows:

"The above figures indicate that there is a waste of water in some of the districts of India. And yet the more favorable ones approach the best conditions developed in California. The capacity of a canal may therefore be fairly estimated by assuming that 12 inches of water over the surface of the irrigable land will, if properly applied, be amply sufficient for the maturing of one grain crop."

Mr. Charles L. Stevenson, civil engineer, a long resident of Salt Lake City, says: "In former years a cubic foot of water per second only irrigated sixty acres; now it is irrigating over one hundred acres. This applies to the whole territory adjacent to Salt Lake City. More careful husbanding gives better results."

He indorses irrigation in the following strong terms: "With irrigation there is never a failure of crops. It may vary from season to season, but a crop is invariably insured." This is very strong language from an engineer who has been watching it practically for twenty years.

In the eastern portion of the United States the average annual rainfall varies from 30 to 48 inches; let us assume the latter—the maximum. This equals 4 inches per month. The crop growing season is generally estimated at 100 days; let us take it at 4 months. This gives 16 inches as the depth of rainfall necessary for a crop.

With care in distributing water in irrigation, there should be no greater waste, or water running off without producing any useful effect, than in ordinary rain, and not as much as in violent summer showers; assuming it to be the same, then 16 inches distributed over 4 months gives a duty of 180 acres to each cubic foot of water per second. This is probably much greater duty than can be expected in the United States for some time; probably not until labor becomes cheaper and water dearer than they are now. At first our farmers will follow their American idea of farming large tracts of irrigated lands as they have farmed the unirrigated, but they will soon learn that more money can be made on a small farm thoroughly farmed and irrigated, than on a large one, irrigated or not.

The preceding is what can be done with water; what is done is another question.

In Southern California, where water is very scarce, and irrigation has been long practiced and studied, results much better than this are obtained.

In the rainless section of Peru, the writer has seen and calculated a duty of 160 acres per each cubic foot of water per second. In Chili, under similar conditions, 190 acres. In both countries the average would be much less.

Mr. Davidson is well known as a careful observer, of high scientific attainments; and his opinion should be taken as to what can be done. The American is a very apt scholar, especially when he is financially interested. When he finds that water costs money, and any economy made in its use will be to his profit, he will soon get as large a duty from water as any other irrigator.

In most cases where water is sold by measurement, a duty of 120 acres per each cubic foot per second can be expected after a few years' experience and improvement in the farmer's distributing service.

Yield of Water From Water-sheds.

Mr. E. S. Nettleton, State Engineer of Colorado, gives the following useful table on the monthly flow of Colorado streams.

"The Annual Discharge of the Cache la Poudre River.

"Area of water-shed above measuring flume is about 972 square miles.* This gives a 'run-off' equal to 31 054 608 cubic feet per square mile—48 522.8 cubic feet per acre—equal to 13.367 inches, which is a little less than the mean average annual rainfall on the plains east of the mountains.

"The mean annual rainfall on Pike's Peak, 1874 to 1881, inclusive, was 33.6 inches.†

"The percentage of monthly discharge compared to annual discharge is as follows, viz.:

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* The elevation of this measuring flume is not given; it is probably about 5 000 feet above tide. The elevation of the water-shed extends from this up to 14 000 feet above the sea.

† Pike's Peak is 14 147 feet high, and about 150 miles south of the water-shed.

January, February, November, December	(estimated).....	4.59 per cent.
March (estimated).....		0.59 "
April.....		1.86 "
May.....		22.55 "
June.....		40.97 "
July.....		18.74 "
August.....		6.63 "
September.....		2.59 "
October (estimated).....		1.78 "
Total.....		100.00 "

This may be taken as a fair sample of the flow of the streams having their origin in the high portions of our mountain ranges.

It appears that in the three months in which the crops are growing, 82 per cent. of the total annual water flows down the stream. This table also shows plainly that no irrigation system is complete, or can work approximately up to the capacity of the stream, without impounding reservoirs to give water for the late, or second, crops. Just how much water, or what percentage of the water, will be required after July, will depend entirely upon the description of crops raised; but there will always be a large demand for water for the corn, hay, and fruit crop; as also for pasturage, commercial and ornamental gardening. This demand for late water will constantly increase, as it is the general tendency of farmers on irrigated land to change from grain, which is generally their first crops, to diversified crops, including fruits; increasing all the time what may be termed ornamental or fancy farming, requiring constant water from frost to frost.

Every engineer in laying out an irrigation system to be fed by rivers of this description, must provide storage reservoirs for the late water that may be required, provided he intends to utilize to the fullest extent the capacity of his stream during the growing season. It will not be necessary to provide all this late water at once, but he should be able to increase it as the demand does.

As the height of the mountains and country supplying the irrigating system with water diminishes, so will the water available for late irriga-

tion decrease. This will oblige the construction of storage reservoirs of greater percentage of the total capacity of the irrigating system.

The proportion of stored water to the whole will be larger in irrigating systems that have their water supply from low elevations or mountains than in those systems that take their supply from high elevations.

Storage Reservoirs.

The cost of storage reservoirs differs very much in different localities and in different geological formations. When Mr. Allen Campbell, M. Am. Soc. C. E., was the Commissioner of Public Works of New York City, he considered the average cost of storage to be $200 for each million of gallons stored. The proposed Quaker Bridge Dam, at the estimated cost, will cost $125 for the same quantity stored. The recent survey for the water supply of Philadelphia makes the average cost in eleven reservoirs, $131.84 for each million gallons stored. A recent survey in Idaho, in exceptional favorable locations, makes the average cost of storage in five reservoirs, 72 135 000 000 gallons, $147 217, or $2.05 for each million of gallons stored. One of these reservoirs will store 52 275 000 000 for a total cost of $50 833, or 98 cents for each million of gallons.

These last are very favorable localities. Basaltic dikes run across the valleys, through which the running water has worn narrow and deep channels, it being only necessary to close up these narrow openings to form large lakes or reservoirs.

Average cost of storing in six reservoirs in Spain, 7 582 000 000 gallons, was estimated at $410 700, or $54.17 each million gallons stored.

At the rate of 180 acres of land irrigated 16 inches deep by 1 cubic foot of water per second, this will require for each acre of land 425 000 gallons for the crop season of four months; say, 500 000 gallons. Where the irrigation is entirely by impounded water the storage facilities must be unusually favorable, or the value of the water exceptionally high, in order to make it pay, but it can generally be used with profit to supplement the running streams late in the season.

The entire investment of the Indian government in irrigation works amounted in 1881 to $86 000 000. The total area irrigated was about 8 000 000 acres. This makes the cost of works per acre irrigated $10.75.

TABLE No. 2.

COST OF SOME IRRIGATING WORKS.

NAME.	COUNTRY.	COST OF WORKS.	
		Per acre irrigated.	Per cubic foot per second for water used.
High Level Canal	Colorado	$10.83	$549.00
Cajon Canal	California	53.33	1 025.64
Santa Clara Valley Irrigation Company	"	9.68	548.82
Riverside Canal	"	52.75	1 507.14
Mussel Slough	"	7.30	583.65
King's River, north side	"	7.18	277.20
Idaho Mining and Irrigation Company (estimated)	Idaho	2.16	189.38
Carpentras Canal	France	35.67	2 830.19
Verdon Canal	"	81.25	15 330.19
Hanares Canal	Spain	46.66	7 500.00
Ganges Canal	India	14.15	.....
Eastern Jumna Canal	"	6.11	.....
Western Jumna Canal	"	10.88	.....

The average cost of bringing water to the land in seven recent irrigation works near Madrid, Spain, was from $30 to $40 per acre.

The entire canal system of Colorado embraces over 800 miles of large size canals completed; about 150 miles projected; and about 3 500 miles of canals of secondary size. The large canals have cost in construction about $5 000 000; the smaller canals about $3 000 000; and the entire system from $10 000 000 to $12 000 000. Total area of land covered by these canals, 2 200 000 acres. Average cost, $5 per acre.

Italy employs for irrigation a total of 24 000 cubic feet of water per second, which irrigates 1 600 000 acres of land. This gives an average duty of 67 acres for each cubic foot per second.

It is estimated that $200 000 000 has been spent within the last seven hundred years to irrigate 1 000 000 acres in Lombardy, Italy. This gives an average cost of $200 an acre, although the average rainfall is 38 inches, with 22 inches in the irrigating season.

In fourteen districts of the Madras Presidency, India, the English found 53 000 tanks or reservoirs of native construction, with an estimated length of embankment of 30 000 miles. Some of these tanks are of large size. For example, the Ponairy, in Trichinopoly, had an embankment 30 miles in length, and a storage area of about 70 square miles; the Veevanum tank had an embankment of 12 miles in length, and an area of over 30 square miles. These dams or embankments are

made of earth without puddle—in one case reaching a height of 108 feet. In the Madras Presidency the average annual rainfall is 35 inches.

Grade and Velocity.

The velocity of the water in the canal should be uniform. It might increase, but in no case should it diminish, as any diminution of the velocity of the current would cause a precipitation of the silt, which would have to be removed from the canal. The engineer should endeavor to deposit as little silt as possible in the canal and all he can on the land, where it is wanted for its fertilizing elements.

The grade should be regulated, in reference to the cross-section of the canal, so as to give a velocity of not less than three, or more than five, feet per second; if less, the silt would be deposited; if more, the water would scour injuriously the banks and bottom of the canal when constructed in light earth or sand. In rock or hard material there is no necessity of limiting the velocity.

Evaporation and Seepage.

This is an ever-varying quantity, owing much to the nature of the ground through which the canals are constructed, and to the care expended on the work. Under most circumstances the evaporation is but a small part of the loss. Mr. Walter H. Graves makes this in Colorado during the irrigating months from .09 to .16 of an inch per day. He thinks that 12 per cent. should be deducted from the carrying capacity in the older canals to allow for seepage and evaporation.

In some of the Colorado canals the loss from these causes is estimated at 50 per cent., which is excessive, and shows that the canal is constructed in bad soil, or that there must be something the matter with the construction. Twenty per cent. ought to be, under ordinary circumstances, a liberal loss from these causes, and this should largely diminish as the banks and bottom of the canal become compact.

Yield of Irrigated Land.

As a sample of the crops that irrigated lands yield, the following extracts are taken from a recent report on the desert lands near Boise City, Idaho, by Mr. A. D. Foote, M. Am. Soc. C. E.

"Mr. I. N. Coston, a member of the Legislature for many years, and

one of the most prominent farmers in the Boise Valley, made the following statements to me:

"'On ten acres of poorest land, with imperfect irrigation, raised 40 tons of red clover hay. Sold 75 000 pounds (1 250 bushels) of onions from 2 acres. Potatoes only gave 200 bushels to the acre. Have raised 1 000 bushels on 2 acres. Have raised 113 bushels of barley on an acre; wheat from 40 to 60 bushels; oats, 100 to 150 bushels; carrots and turnips equally good with potatoes. Connecticut Flint corn will grow well, especially on the higher benches; have raised 60 bushels to the acre in the bottoms. Prunes, the Germans say, grow better than in their own country. Apples, pears, peaches, plums, apricots, cherries, etc., as good, if not better, than in the most favored spots in California. The elm, soft maple, black walnut, locust, etc., make our best shade trees.'"

R. E. Strahorn says: "Idaho valleys cannot be excelled by any region east of California for the production of fruit. Apples, peaches, pears, nectarines, apricots, plums, prunes, grapes, and all the small fruits are produced in the greatest abundance and of a quality unsurpassed. The sage-brush lands, naturally the very emblem of sterility and desolation, are in a few years turned into the finest fruit farms with less trouble than would attend a similar transformation on the wild prairies of Iowa or Nebraska. A prominent fruit-grower estimates that 20 000 large fruit trees have been set out annually for the past 5 years in the valleys surrounding Boise. Several of the orchards in this locality produce from 25 000 to 40 000 bushels of fruit each annually, there having been but one failure in the crop for ten years. General L. F. Cartee, ex-Surveyor-General of Idaho, has 40 varieties of grapes in his vineyard, none of which have ever failed to bear a full crop, save the Catawba. John Krall, in the suburbs of Boise, has 125 acres in fruits (20 000 trees), embracing all the varieties known in this latitude. His production last season was 500 000 pounds. He finds no fruit insects yet, and pears are never troubled with blight or other diseases."

The writer can bear evidence to these statements about Idaho. Last August he examined, professionally, into the advisability and practicability of irrigating a large tract near Boise City. He had never seen anywhere larger crops of hay and all kinds of fruits, especially apples and plums. The wheat had been harvested, but, judging from the stubble, there was no reason to doubt the reported large yield. In fact all kinds of grain, vegetables and fruits of this latitude appeared to grow

rapidly and yield abundantly. Boise City was visited with a large fruit merchant from Oregon. Though Oregon is celebrated for its fine apples, this merchant said he had never seen anywhere apple orchards equal to those near Boise City in quality and yield.

All this land produced nothing but sage-brush before it was irrigated.

One of the most extensive and profitable uses of irrigated land will be to grow hay for feeding cattle during winter. Without feed during the winter seasons it is hardly possible for the grazing section of the West to be more heavily stocked than Colorado is at present, but with reserve food in stacked hay for the winter or dry season the stock can be very largely increased.

During a recent trip through the stock range country, stockmen assured the writer that they could afford to pay from $6 to $8 per ton for hay for winter feed and fattening purposes, as the hay can be cut and stacked by contract for one to two dollars per ton. An acre of irrigated land will yield from four to six tons annually. This gives at once a large and profitable business to the farmer. In the northern part of the dry belt, Idaho, Montana and Wyoming, the summer feed is almost unlimited, and with the reserve of winter food the number of stock can be very largely increased.

Profits of Irrigation.

This is very variable, depending upon the crops, soil, climate, market, etc. It can however be safely asserted that crops will average one-half larger on land that can be thoroughly irrigated whenever requiring water, than on the same description of land depending upon the uncertainties of the usual rainfall, say 40 inches annually. This is shown by the great attention paid to irrigation, and the large amount of money spent in France and Italy to bring and distribute the water. Irrigated lands not only produce much larger crops, but the large crops are constant, without failure from drought. During dry seasons, when the farmers on unirrigated lands have short or no crops, the farmer on the irrigated lands has large crops, which he sells at famine prices.

The question is frequently asked how farmers living in the interior of the continent, far from all markets, can afford to pay the annual water rent for irrigating water, and the expense of distributing it. The following are the principal reasons why he can do this.

First.—He is always certain of a large yield.

Second.—He loses no seed, labor or crop by dry or wet seasons.

Third.—The crops are grown and harvested under a bright, clear sky. No loss from storms or rains before or at harvest.

Fourth.—Crops grown under these circumstances are always harvested in good condition, and are generally of superior quality; consequently bring higher prices.

Fifth.—The railroads passing through this dry section have very wisely adopted low rates on grain and other staple products. This puts the farmer on these irrigated lands in a more profitable position than the Eastern farmer on unirrigated lands. The extra yield of irrigated land, in large unfailing crops of superior quality, more than pays the extra freight.

Sixth.—Irrigation makes the farmer entirely independent of the weather; he can make his crop early or late at will. He can have his land wet or dry, as desired, for plowing, cultivation or harvesting.

Seventh.—Another great advantage is the enriching silt that is brought down and deposited on the land by the water from most rivers. With this it is never necessary to use manure or fertilizers; by this the soil of cultivated lands along the Nile has been kept up, notwithstanding the thousands of years it has been cultivated. In all countries that practice irrigation, there are many instances where farmers pay high prices for water containing silt, when clear water could be had at much less cost. A prominent Idaho farmer said: "I would rather give two dollars an acre water rent for muddy water than one for clear."

In France, notwithstanding there is an average heavy rainfall, irrigated land is worth more than double what the same land would be unirrigated.

In Colorado, land that can be irrigated sells for $15 to $50 an acre, with an annual water rent of $1 50.

William Hammond Hall, M. Am. Soc. C. E., State Engineer of California, says in his last official report: "In California, lands purchasable at $3 to $10 without opportunity or reasonable hope of irrigation, command $50 to $200 per acre when water is brought to them and they have the privilege at hand to receive and pay for irrigation."

Irrigated land in Southeastern Oregon sells for $45 per acre.

TABLE No. 3.

VALUE OF IRRIGATED LAND.

SPAIN.	VALUE PER ACRE.		ANNUAL RENT PER ACRE.	
	Irrigated.	Unirrigated.	Irrigated.	Unirrigated.
Alcanadre	$375	....	$45	$2 25
Zamora	175	$70	....	....
Near Madrid--				
1st Class Land	640	160	....	....
2d " "	500	100	....	....
3d " "	360	60	....	....
4th " "	300	30	....	....
San Fernando	....	25	25	....
Castillon	700	50	....	....
Valencia	400 to 900	80	....	....

Mr. J. F. Bateman, the celebrated English engineer, in a paper read before the Institution of Civil Engineers, in 1868,* says:

"The fee simple of land in Spain sold from £3 to £8, when not irrigated; the same land, when watered, sold at from £60 to £200 an acre. * * * On one side of a ditch there would be a field producing abundant crops of every sort, and on the other side, for want of water, the land would be a barren waste. * * * The rate to be paid for water distributed from the Henares Canal, amounted, in English money, to 28s. an acre annually. For that the tenants were entitled to twelve irrigations in a year, each irrigation amounting to 2½ inches in depth of water upon the ground, or a total depth of 30 inches in the course of the year.

"That rate was cheerfully paid, and well it might be, because the increased value of the land was at least seven-fold, and he should be nearer the average if he said ten-fold; for land which sold for £6 before irrigation, would sell for £60 after it was irrigated."

This is very strong evidence in favor of irrigation. Perhaps no one is as well posted on it as Mr. Bateman, as he constructed the Henares Canal and many other large works in Spain.

IRRIGATION AND NAVIGATION.

Many of the large canals of India and Europe were built with the intention of combining these. Experience has not shown this to be

* Proceedings of Institution of Civil Engineers, Vol. XXVII, page 512.

good practice, as it complicates the question very much, and at the same time makes the work much more expensive by requiring locks and larger cross-section in order to have less current. This causes the silt to settle in the canal, requiring labor to remove it, and deprives the water of the much-desired fertilizing elements. It is doubtful if the two systems can ever be advantageously combined in this country. This combination has in many cases added very largely to the cost of the Indian and European irrigation works.

Distribution of Water.

Distributing or dividing the water has been one of the most difficult problems connected with irrigation; all have felt the want of a proper measuring instrument. For the want of this, different systems have been followed, such as charging for the water so much an acre, or crop—thus leading to constant trouble and misunderstanding between the buyer and seller; and has made the buyer, as a rule, demand and consume more water than is necessary or desirable. All persons interested in irrigation agree that the water should be sold by measurement, provided a satisfactory apparatus for measuring it could be found. The water-meter invented by Mr. A. D. Foote, M. Am. Soc. C. E., described in a paper recently read by him before this Society, seems to supply the deficiency, as it works well; by prolonging the weir, it can be made as correct as desired. It can be made by any carpenter from rough planks. It is simple, cheap and accurate.

In Italy and Spain the water is sold by measurement; in India by a fixed price per acre or crop; this last has been found to be the cause of great waste, in some cases being estimated at ten times the necessary quantity.

Riparian Rights and Ownership of Water.

This question has become a very prominent one in California since water has become so valuable for irrigation. From the settlement of the country it had been the custom for the mining ditches to hold absolutely all the water actually appropriated by diversion or used. Later, irrigation ditches followed the same custom, believing that custom made law; a great many millions of dollars had been invested in mining and irrigating ditches. As water became more valuable, and in greater demand, those who claimed riparian rights to the water appealed to the

courts to prevent its being diverted to their injury. After long litigation, the case was finally decided last winter by the highest court in favor of the riparian owners, thus reversing at one blow the practice of forty years, where millions had been invested, and on which two of the principal industries, *i.e.*, irrigation and hydraulic mining, had been founded. The situation was so grave that a special session of the Legislature was called to see what could be done under the circumstances. The writer has not fully heard what was done.

Being interested in the matter, he recently obtained an opinion on riparian rights from a prominent legal firm who have very large experience on the subject. As this may be of service to engineers interested in irrigation work in our Western States and Territories, the following full extracts from the opinion are given.

"The provisions of the Idaho statute are recognized and authorized by Sections 2339 and 2343 of the Revised Statutes of the United States The right to sell and dispose of water is given by the act of the Legislative Assembly of Idaho before referred to.

"The laws of Idaho are intended to carry out the legislation of Congress authorizing the appropriation of water for irrigation and other useful purposes to the fullest extent.

"They entirely abrogate the common law doctrine of riparian rights, and subject all the waters running through the public lands of the United States to appropriation.

"In this respect the legislation of Idaho, and many other of the Pacific Territories, has gone beyond that of California and Nevada, and the recent decision of the Supreme Court of California in Lux *v.* Haggin would have been impossible under our statutes. * * * It is plain, from the foregoing summary, that in the State of Colorado, and in the Territories of Montana, Idaho, Dakota, Wyoming, New Mexico, Arizona and Utah, the legislation has wholly abandoned and abrogated all the common law doctrines concerning private property in streams and lakes, and concerning the 'riparian rights' of 'riparian proprietors,' the statutes in express terms apply to all streams, as well those running through public lands as those bordered by the lands of private owners.

"No exception from their operation is made in favor of persons owning lands on the banks of a stream. Under these statutes no proprietor derives any legal benefit or advantages from the fact that his

land is immediately adjacent to a stream. Unless he has made an actual appropriation and diversion of its water for the use of his own land he is liable to have perhaps the entire stream appropriated and diverted away for the benefit of a proprietor whose land is situated at any distance from the stream."

From this opinion it appears that California and Nevada have not by special act abrogated or repealed the old common law of riparian rights, while most of the Far West States and Territories have done so.

This legal opinion was obtained, for use in Idaho, from one of the most prominent legal firms there; but it also covers most of our Western States and Territories. This opinion has been confirmed by a New York firm of high legal reputation.

Railroads and Irrigation.

This desert section of the United States is traversed by five transcontinental lines; the aggregate length of railroads in it is about 12 000 miles. Competition has divided up the business and reduced rates so, that now there is but little money in the through traffic. The railroads must look to local business for their revenue; that is, from mining, cattle raising and irrigated farming. The first is uncertain; cattle will always be a good business, but it will not be very large. Colorado is very heavily stocked with cattle, horses and sheep (many say too heavily), yet the annual shipment of these is only about three tons per each square mile. Farming, which can be followed very extensively along some of the lines of railroad by means of irrigation, will soon become a source of great revenue to those roads. Manufacturers will follow farming here as they do in most other places.

The farmers upon irrigated lands are comparatively more prosperous than upon unirrigated lands; they soon become infatuated with the land that always produces large crops regardless of the seasons or rains. All the money that they make goes back to the farm in additional comforts and improvements, all of which must pay tribute to the railroad in freight. The tendency on irrigated lands is towards small farms and dense population. In the irrigated district of Murcia, Spain, there are 2.6 persons to each acre. In many other irrigated districts in Spain there are over one person to each acre. The farmers on irrigated

lands are comparatively prosperous, and are good patrons of railroads.

It is estimated that one acre of irrigated land produces, directly and indirectly, over one ton of freight from each acre annually; or over two hundred times more than the same land would if used without irrigation for raising cattle.

DISCUSSION.

T. C. CLARKE, M. Am. Soc. C. E.—If Mr. Dorsey's opinion is correct, that "irrigation can be introduced profitably in most places and in most climates," several interesting inquiries suggest themselves.

For instance—why cannot the disposition of sewage be united with irrigation and thus solve one of the vexed questions of modern engineering?

As a safe estimate, assume that one cubic foot of water per second will irrigate 100 acres. One cubic foot of water per second corresponds to an annual discharge of 31½ million cubic feet.

Authorities on sewage state that the amount of sewage discharged per head of population is six cubic feet per day, or 2 200 cubic feet per year. A town with a population of 10 000 would discharge 22 000 000 cubic feet of sewage annually, or enough to irrigate 63 acres of land.

The great difficulty with the disposition of sewage above ground as liquid manure, is the unsanitary condition of the land and the nuisances arising from evil smells. In addition to this, the above statement itself shows why it does not pay, as the land is too limited in amount.

Suppose even the town of 10 000 people dilutes their sewage and treats it not as liquid manure but as water of irrigation. Suppose they mix with it ten times the amount of water, procured as other water is. They can now irrigate 630 acres of land without bad smells or other objectionable results.

The general question will be: Can the additional cost of handling ten times as much water as would remove the sewage be paid for as irrigation of crops and absence of nuisances?

The particular question to be worked out in each separate case is: Will it pay to irrigate —— acres of land, and at the same time properly dispose of the sewage at a cost of $—— for pipes, pumps, pumping, etc.?

If Mr. Dorsey's views are correct, the town of 10 000 people could afford to spend—630 acres at $200 per acre = $126 000 and receive a return in irrigation alone. The amount of water procurable and the population would be the controlling elements.

A. D. FOOTE, M. Am. Soc. C. E.—Mr. Dorsey, in his valuable paper on irrigation, mentions several cases for the wide variation in its duty of water, as shown by his table following.

It seems to me that by far the most important cause is the method employed in delivering water to the irrigator. Throughout all irrigating countries it will be found that the duty of water is large or small precisely in accordance with the incentive offered to the irrigator for economy in its use. Where water is measured out at so much per unit there the duty will be large; where it is sold by the crop or area watered, there will there be waste and low duty.

Neither climate, soil, crops, rain-fall, nor the intelligence of the irrigator, will in the least account for the vast difference between the duty of water in Spain and Colorado. Spain gets a duty of 140 acres per cubic foot per second, and Colorado one of 56; and the sole reason is that in the early days it was the custom in Colorado to use and waste water at the aforesaid rate. When the later and larger canals were built, they adopted the custom in vogue and encouraged it by selling water by the acre irrigated. At the same time, as if dimly seeing an error in their method, some of the canals measure out their water, but at the rate of $\frac{1}{50}$ of a cubic foot per second per acre.

It was probably difficult to establish an increased duty, as in many cases water was offered as an inducement to buy land. As time goes on it will become more and more difficult to make the change. Changed it must be, or half the agricultural land of Colorado will remain forever barren.

In the arid portions of our own country, a large duty of water will become of great importance, and in constructing new works engineers will save immense trouble in the future if they so plan them as to make it the interest of the individual irrigator to get a reasonable duty for water from the outset.

The storage reservoirs in Idaho spoken of by Mr. Dorsey, were located by me. One very important item in their construction, which accounts in a great degree for their cheapness, and which he omitted to

mention, is that in each case a natural waste weir exists. The dams, cheaply constructed of earth (with the proper masonry culverts through them), are high enough to send all waste water over the solid basalt dikes, which are indestructible and require no work or expense.

In the table of various irrigation works given by Mr. Dorsey, I think the wide divergence in costs given by him may be largely attributed to the right of way expenses and to the use of the canals for other purposes than irrigation; not, as is often rather derisively assumed, especially by foreign engineers, because we build "flimsy ditches." In this country the right of way is practically free; the Government gives it over its own land, and lands already occupied, through which our canals are likely to be built, are sufficiently compensated by the water privileges supplied.

As an instance I may mention that in laying out a canal in Idaho, which, with its branches, was several hundred miles in length, only one tract of occupied land was crossed, and the right of way over that was freely given for the water right at the regular price.

Compare this with Baird Smith's picture of Lombardy:

"The whole country is covered with them (minor canals) as by a dense network. At all levels, and by the use of various ingenious devices, they pass over or under or through each other in such ways as to preserve individual rights uninterfered with, though the result, to outward appearance, is a system of such marvelous complexity as to make the observer conclude it must lead to interminable disputes."

It may be well to state that the multiplicity and complexity was brought about by the laws of the country, which caused each landed proprietor to build his own private channel from the main canal, and required him to pay for the right of way and make all crossings. All this could have been avoided if the system had been laid out at one time, as would be the case in the deserts of this country.

The canals of India (and largely those of Europe) were built partially for navigation and water power, and consequently cost much more than if built simply to pass water through.

I quite agree with Mr. Dorsey's opinion in regard to velocities for irrigating channels, and wish he had gone further and given us the manner of determining them.

There seems to be a wide difference of opinion among engineers in regard to the proper formulas in these matters. I well remember being

told by a Member of this Society that the formula $V = 90\sqrt{R\,S}$, which I was using for a large canal, was "all wrong;" the canal would carry a third more than I anticipated. I was somewhat startled, but not convinced.

Captain Allan Cunningham, R. E., in his "Rourkee Hydraulic Experiments," gives the only records known to me of the absolute capacity of a large canal in its ordinary earthen channel. These results have been of great value to me, and I wish he had devoted his whole time to the ordinary channel and let the Solani Aqueduct alone.

Giving his values for R and S in the above formula, I find the resulting velocity agrees remarkably with his observed velocity. Whether this agreement will continue with increase in grade is a question which I hope to see satisfactorily answered. I believe in giving the greatest velocity permissible with safety to an irrigating channel, even if it should occasionally require slope wall or the loss of land in consequence of the extra grade.

The fertilizing silt which swift-running water usually carries is eventually nearly as valuable as the water itself. Without it irrigation in this country would soon be a failure. No land can stand continual production without enriching, and it will be many years before our Far West farmers can afford the ordinary artificial manures. The silt with which our Western rivers is loaded in the spring and summer is so valuable, that the land irrigated by it improves even under the heaviest cropping. I myself know of many instances proving this.

Baird Smith speaks of the great value of silt in Italy, and of the difference in price between the clear and silt-bearing waters. Moncrief gives striking instances of the building up of worthless land entirely from the silt deposited upon it, making it of great value. Wilson, in his "Irrigation in the South of France," speaks of the clear, cold waters of the Sourgues as being refused by the (land) proprietors when they could be had for nothing, and the waters of the muddy Darance bought instead. It is not altogether the silt held mechanically by the water which renders it valuable, however; matter held in chemical solution is sometimes considered the best part of the silt.

There is, I believe, no doubt whatever that irrigation is profitable to the irrigator. Arguments or facts on that point seem to me superfluous and almost absurd; but there is at times serious doubt as to whether irrigating channels ever will pay for their construction, except

by indirect returns from the increased prosperity of the country through which they flow.

This has been the case with many foreign canals, which were built with that expectation by royalty or large land-owners.

Canals in this country are built either by individuals or corporations, and are often owned separate from the land. This may be the reason why they are almost invariably large interest-paying properties. Take the average for the whole State of Colorado; the irrigating works costing five dollars per acre, and the average price for water one dollar and a half per acre, gives thirty per cent. yearly interest on the investment, out of which the cost of repairs and distribution must be taken. Ten per cent. is an ample estimate for these, leaving twenty per cent. for the canal owners. Certainly a very good showing, when we consider the number of canals, with their different managements.

On the question of riparian rights there seems to be a settled opinion among Eastern people that it is an outrage to deprive a man of the privilege of having a river "flow unvexed to the sea" by his door. It is difficult, and may be impossible, to change this opinion, which has been the common law of a people for generations, without the aid of object-lessons, so to speak. If any one who thoroughly believes in riparian rights could but walk to the top of a *mesa*, in sight from the desk where I am writing, and look over the country below him for ten minutes, I am quite positive he would admit that riparian rights were not only inapplicable to such a country, but would be most unjust and tyrannical. From that *mesa* he could see the Boise River flowing for sixty miles through a valley only two or three miles wide, between steep *mesas* or banks, scraggy cotton-woods and willows along the river, and scattering farms along the banks, each with its little ditch carrying water to the fields and orchards. In June the turbulent cold flood from the melting snow tears away the feeble gates and dikes, and its brawling, ever-changing channel menaces the farms with sudden overflow. The orchards and farms are green and beautiful, and the crops are enormous; but away to the south and west stretch miles and miles of brown, gently sloping plain, a dreary waste of uninhabited desert, more than half as large as Long Island Sound. Surely it is not arbitrary, unjust or injurious in any sense to take this water out from the little valley, where it is not wanted (except that trifling portion needed by the farmers, and which the law protects them in), spread it over those

vast plains, and eventually, like the waters of the Ticive "fertilize and stimulate the soil to such a remarkable degree as to render the region through which it passes one of the most productive and densely populated in the world." But the law itself is not arbitrary or unjust or for the benefit of monopolies. It is very carefully adjusted to the natural laws and wants of the people where it is in force. The riparian right doctrine is entirely abrogated, and it is an absolute necessity that it should be. The other water laws are well defined and distinct, and require of the appropriators of water certain conditions, which, if not adhered to by them, render their appropriation void.

The principle of the law is that the water belongs to the entire community, and the entire community must be allowed the use of it.

Canals are treated in some respects as common carriers. No monopoly can take the water and waste it, nor sell it one season and take it away the next, and thus ruin the irrigator; nor make the price prohibitory; nor do any unfair or unjust thing, simply because it has built a canal to carry water.

As to litigation. In the commonwealths of New Mexico, Arizona, Colorado, Utah, Wyoming, Idaho, Montana and Dakota, there is less litigation to-day, and less fear of it in the future, over water rights than over any other class of property of equal value and interest. In all the above named commonwealths from January 18th, 1884, to October 16th, 1886, there were but seven cases of litigation concerning the use of water, and all these were interpretations of the law, and did not question the law itself.*

The cases were as follows:

1884. Colorado, Sieber et al. *vs.* Frink et al.
1885. " Golden Canal Co. *vs.* Bright.
" " Knoth *vs.* Barclay et al.
1886. " Lerimer Co. Reservoir *vs.* People.
" Idaho, McCarty *vs.* Boise City Canal Co.
" Utah, Lehi Irrigation Co. *vs.* Moyle et al.
" Arizona, Clifford et al. *vs.* Larrien.

* In the foregoing I do not wish it to be understood that there were no actions in the lower local courts; there were the usual disputes about this kind of property in these courts, as about other kinds. Any case involving a principle or proper interpretation of the law would go to the supreme courts of the commonwealths which are the courts referred to.

The case of Lux *vs.* Haggin, in California, was decided by four judges against three, and the main points at issue could never arise in any of these other commonwealths.

The following is the syllabus of the case of Clifford *vs.* Larrien, decided in Arizona last summer. This would look as if riparian rights were on ditches rather than on streams.

"The owners of irrigated lands may enjoin one who wrongfully directs water from an irrigated ditch to their injury, when the ditch is the property of another.

"The owners of lands irrigated have rights in water flowing in a ditch, though the ditch be not their property."

In this case other parties were taking the water from the stream above the mouth of the ditch in question which had prior rights. The ditch-owners refused to bring action. The land-owners who bought their water from the ditch-owners then brought suit, with the above result. The court held that the land-owners were the injured party as well as the ditch-owners.

GEORGE G. ANDERSON, C. E.—Probably the most important point raised by Mr. Dorsey in regard to irrigation enterprises, at least as applicable to Colorado, is the necessity of providing storage reservoirs for the late water that may be required. This demand for late water is increasing here, as the average of grass crops that need water from frost to frost increases. Owing to a number of circumstances, it is evident to most observers in Colorado that the period of greatest supply in the rivers is becoming earlier every year. This is due mainly to the fact that the Rocky Mountains have been almost entirely denuded of timber, and the consequence is that, despite the fact that there is always, or almost always, a sufficient snow-fall during the winter, should the spring happen to be open and mild, the snow passes off very rapidly thus unsheltered. The season of 1886 gave very ominous evidence of the disaster this denuding of the forests may entail to the irrigation enterprises, where they depend on river supply only. The spring being mild, the rivers in the northern part of the State were in high water at least three weeks earlier than usual, and before the main supply for irrigation was required. Early in July, at the height of the irrigation season, the rivers were comparatively low. The demand for water was largely in excess of the supply, and had it not been for providential rains, which cannot always be relied on at that season of the year, serious losses might have ensued to growing crops. The Federal Government have now taken steps to prevent, in part at least, this wholesale destruction of timber,

when it is probably too late. It would have been well to have enforced lumber-men to plant where they cut, and that can even now be done.

But the building of reservoirs in the mountains to impound the water involves legal as well as financial and engineering questions. It is very doubtful, in the present agitated state of feeling on these questions, if public opinion would permit canal-owners building such reservoirs to be used as aids for individual enterprises, and it is equally doubtful if the State would appropriate any sum to be spent in the construction of such works, even resulting, as it would, in the general good. The Federal Government might be and has been appealed to to make appropriations for such works for States depending on irrigation, but it is apparently impossible to impress upon Eastern legislators the necessity of doing anything of this kind to develop the growth of Western States, not, probably, because they are prejudiced, but because they do not appear able to comprehend the importance of these urgent matters.

As far as Colorado is concerned, it is very doubtful if individuals or corporations—owners of canals—would by themselves venture on such work, considered purely on a financial basis, as at present such enterprises as these are can hardly be classed as revenue-bearing, considered simply as means of conveying and distributing water to farming land.

In regard to the question of evaporation and seepage, Mr. Dorsey regards the estimate of 50 per cent. loss from these causes on some Colorado canals as excessive. It is undoubtedly excessive, and it is as undoubtedly true, in some instances at least. General Pierce, the engineer for the Denver Water Company, an old resident of Denver, and a gentleman who gives close attention to such questions, gave evidence recently in a lawsuit, that on two different occasions he had measured the ditch supplying the City of Denver with water for irrigation and had found on one occasion a loss of 50 per cent., and, on the other, a loss of about fifty-two per cent. The construction of this canal, it may be said, is not of the best. The writer made measurements on the high line canal in the middle of July (1886), and found that where 156 cubic feet per second were passing into the head-gates, only 80 cubic feet per second were passing a point 45 miles from head-gates, and no water was used for any purpose in the intermediate distance. This was during the very hottest and dryest period of an unusually hot and dry summer in Colorado. The soil through which this canal passes is in many places very pervious. There are long stretches

of fine sand and in places the canal bottom is on rock badly fissured. The alignment of the canal is very crooked, and no doubt a great loss is experienced from this source. It is to be expected that this serious loss will gradually diminish as the canal bed and sides become compact and puddle naturally. But to estimate a smaller loss from these causes than 25 per cent. would scarcely be wise.

Mr. Dorsey states that the duty of water in Colorado is fifty-six acres per cubic foot per second. This is so at present, but the remarks quoted from Mr. Stevenson, of Salt Lake City, in regard to duty in Utah are applicable to Colorado. It is reasonable to expect that more careful husbanding will greatly increase the duty. There can be very little doubt that in this regard a great deal depends upon the irrigator's knowledge of the economical use of the water, and it is fair to say generally, that the user of water in Colorado is not yet fully alive to this matter. There are exceptions to this, but it must be remembered that the great increase of irrigation is of recent date, and the economic value of water is only appreciated by continued experience. In many instances, too, the farmer is not altogether to blame; there is not much encouragement given him to save water. Though the water is in most instances sold by measurement, it is on the basis of a certain quantity per acre, and the farmer is liable always to take the full amount for which he has paid. It would probably be better to sell and distribute the water by measurement in quantity without any reference whatever to acreage, and thus give farmers an opportunity of economizing. There are, however, on the other side many reasons in favor of the present system of distribution by acreage, at least at the commencement of large enterprises. When it can be clearly demonstrated that the system of measurement by quantity alone will tend to greater economy and be to the mutual advantage of buyer and seller, it will speedily be adopted. And, as a first step to that, a simple, accurate, and inexpensive system of measurement must necessarily be adopted. That has still to be supplied in Colorado.

Mr. Dorsey has ably stated the advantages of farming by irrigation; it would be difficult to do so more tersely.

The value he gives of irrigable lands in Colorado is fully within the limits. Such within a radius of ten miles of Denver rate as high as $75 to $100 per acre, with all water privileges secured.

In the opening paragraph of his paper he says, "perhaps some few meadow and bottom lands would not be improved by it."

This raises another important consideration—the necessity of drainage accompanying irrigation. The writer knows of large tracts of bottom lands which, comparatively dry and valuable before irrigation of the uplands was prosecuted to any extent, are now wet and swampy and considered valueless. They are not really so, however, and only require judicious draining to be made as valuable as the uplands. Several cases are known to the writer where drainage has been followed with most satisfactory results, and the importance of such work will soon be recognized.

Professor EDWARD MEAD (Colorado Agricultural College).—The State of Colorado probably contains the largest and most prosperous irrigated district in the United States. It owes its prominence to several causes, the most prominent of which will be mentioned:

First.—The natural advantages of the country for the building of canals, which have rendered their engineering and construction, as a rule, exceedingly simple and cheap.

Second.—The surprising fertility of the soil, judged from its unpromising appearance before being irrigated.

Third.—The superior local market afforded by the mining camps. The demand for most agricultural products is as yet far greater than the supply, and, as the uncultivated region between the irrigated district of this State and the non-irrigated lands of Kansas affords farmers here a protective tariff in the shape of railway charges, prices have been very remunerative.

Fourth.—The beneficial character of much of the earlier irrigation legislation, which, abolishing the doctrine of riparian rights and making the right to water depend on priority of appropriation and use, has freed us from the dangers and perplexities which now beset California.

Comparatively little engineering skill was required in the construction of the earlier canals east of the Rocky Mountains. The surface of the country has a continuous and comparatively regular slope to the east and southeast, varying from ten to twenty-five feet to the mile, and having been but slightly affected by erosive action, there are no deep ravines or abrupt slopes. But few flumes or embankments, therefore, were required. After leaving the foot-hills the streams flow over shallow beds, whose banks rarely exceed a height of ten feet. The head-gate of

the canal is located in some favorable bend, with the bottom of the canal excavated below the bed of the stream, which device obviates the necessity of a dam, or, at most, only a temporary one for low water. The engineering work connected with the construction of some of the larger canals recently built has been both important and difficult. One now being built in the western part of the State diverts the water of the Doloris River into the drainage area of the San Juan by a tunnel one mile in length.

The majority of devices at present employed for measuring water are exceedingly crude and unsatisfactory. The law defining the "statutory inch" is imperfect; the name of the unit is unfortunate, and its use not being compulsory we have almost as many measuring devices as we have canals. The majority are faulty in design, and in many cases worse in matters of construction and location. The use of the term "inch" has led to much confusion, not only among farmers, but judges have rendered decisions in which the term inch only meant the number of square inches in cross section, without regard to the form, size, grade or character of the ditch. One of the great needs of our system at present is the establishment by law of some form of measuring device which shall be reasonably accurate and whose working can be easily understood. The invention of Mr. Foote is an excellent one, but I am at a loss to understand how it could be employed on our large canals. At present all our measuring-boxes are made of wood, but it is to be hoped that masonry and iron will ere long be substituted.

Surface irrigation, either by flooding or by running the water in open furrows, is the universal method of using water. It is universally conceded that sub-irrigation would be a more economical method, but so far the cheapness of land and water, and the high price of pipe material, have prevented its adoption.

What is especially needed in this State is a reform in our present methods of selling water, and laws to protect the users of water against the encroachments and abuses of canal companies. There are at present no adequate laws regulating the price to be charged for water or the manner in which it is sold.

The practice which generally prevails is for ditch companies to sell what are known as "Perpetual Water Rights." The essential features of these contracts are that the ditch company sells to the farmer a perpetual right to enough water from their ditch to irrigate a prescribed area,

usually forty or eighty acres, subject to a number of provisions about as follows:

"The amount considered necessary to irrigate the area for which the water right is sold shall in no case exceed a certain specified volume, and the ditch company cannot be required to furnish more than this amount."

"The ditch company shall not be held liable for failure to furnish water by reason of accident to ditch or drouth."

"That the buyer must use the water on the area for which the 'right' was purchased. Hence if the purchaser of an eighty acre 'water right' could, by economy, make it water one hundred acres, without exceeding the maximum volume allowed, he is estopped by his contract from so doing."

The cost of these "rights" has risen steadily with the value of land from three to five dollars per acre under the earlier canals, to from ten to twenty-five dollars per acre at present. This increase in price is not due to increased cost of construction, because in many cases the reverse has been true, but to the fact that ditch companies, in the absence of legal restraints, have been in a position to reap the full benefit of the rise in the value of land. As land without water has a very small market value, and is almost wholly unproductive, the farmer, as a business proposition, can afford to pay almost as much for water alone as his land and water will bring. Accordingly, when land with water sold for ten dollars per acre, water-rights sold for five dollars per acre. When land with water advanced to twenty-five dollars per acre, water rates rose to fifteen, etc. The unlimited license afforded ditch companies in the amount of their charges for water, has made irrigation enterprises a profitable field for investment, of which capital has not been slow to take advantage, the result of which is that canal-building has largely outstripped settlement.

The objections to this system are so obvious as to scarcely need mention. Among the more important may be mentioned:

It is unjust, in case of failure to furnish water, which may result from drouth or mismanagement of the ditch. The farmer loses his crop, while the ditch-owner reaps the proceeds on the money received for the water right.

It offers no incentive to economy in the use of water, but, on the contrary, has been a constant inducement to extravagance and waste.

The high price of "water rights" requires the outlay of a larger sum of money to begin farming than the average settler can command, or the incurring of a greater indebtedness than is prudent in attempting a new system of farming, all of which has operated to retard emigration and settlement.

Of the measures of reform which to me seem necessary, I can only indicate a few.

Instead of a large outlay at first for a perpetual water-right, water should be sold by an annual rental or charge, and the farmer only required to buy or pay for the actual quantity necessary to irrigate his crops. In case a ditch company failed to furnish water, no payment should be exacted. In this way, in seasons of scarcity, both farmer and ditch-owner would bear the burden of failure; as it is the farmer bears it alone.

We should have a standard unit of water measure and a standard measuring device, whose use could be required by either farmer or ditch company.

I am convinced that the "duty" of water for this State, as quoted by Mr. Dorsey, is erroneous, being much below the truth. It was the generally accepted amount in the beginning of irrigation, when the duty was much lower than at present, and, in the opinion of the writer, was too low then, because based on the maximum amount required during the short season of wheat irrigation rather than on the average duty for one hundred days. During the past three years the writer has been employed, through the greater part of the irrigating season, in making measurements for the State of the actual carrying capacity of irrigating canals, and, as a result of his observation and experience, is confident that the majority of farmers do not use more than one-half the amount of their estimated water right.

The daily discharge of the Cache La Poudre has been recorded for the past three years. In 1886, nearly the whole of the discharge was required for irrigation. The amount of land under cultivation on this stream can be closely estimated, and, making no deduction for the portion of the discharge which escaped without being used, or that lost in canals and in the river by evaporation, the duty was one hundred and ninety-three acres to each cubic foot per second. The writer has also observed, in a series of careful experiments now being carried on at the Colorado Agricultural College, that, while evaporation from water sur-

face is much more rapid here than in the Eastern States, the evaporation from soil surfaces scarcely equaled those reported by Beardmore for the rainy districts of Eastern Europe, showing that the soil has to an unusual degree the power of retaining moisture. The average duty of water will not probably fall below one hundred acres, and in many parts of the State is much higher.

It would be a difficult matter to state adequately the benefits which irrigation has conferred on the State. To properly appreciate them one should see the barren, treeless plains above the ditches, and the thriving bounteous fields below. From the room where this is written can be seen fields that have yielded seventy bushels of wheat and nine tons of alfalfa per acre. On the experimental grounds of the Colorado Agricultural College wheat has yielded ninety bushels per acre. These are, of course, exceptional yields, but they are such as any agricultural section can afford to be proud of. And this was once one of the most unpromising portions of the "American Desert." The average yields of small grains and grasses are believed to exceed those of any non-irrigated State, with a certainty of success. No farming community is more contented and prosperous than that of this State as a whole, or more sanguine of future success. Land with water sells from $25 to $150 per acre; without the water it can hardly be said to have a market value.

It was once supposed that fruit could not be grown, but at Fort Collins, in the northern part of the State, at an elevation of five thousand feet, the Hon. W. F. Watrous gives me the following statistics of his yields in fruit culture:

He has gathered one-half ton of grapes from seventy vines four years old; eight bushels of currants from a row of bushes two hundred feet long; also an equally large yield of gooseberries. His largest yield of strawberries, eight thousand quarts per acre; this on heavily-manured prairie soil. He has now thirty varieties of standard apples, and at a recent horticultural exhibit in Denver, one hundred varieties of standard apples grown in the State were exhibited. The success of agriculture here, and the consequent cheapening of its products, has made it possible to more rapidly and successfully develop the mineral resources of the State. Without the home-grown products, the cost of living in mining towns would be so enhanced that hundreds of mines that are profitably worked to-day would be closed.

It has given employment and restored to health hundreds of men who were hopeless invalids in the East.

We are just awakening to a proper realization of the magnitude of this interest, and to the advantages of better practices and better laws. With them will come a more rapid settlement, while the unsurpassed healthfulness of the climate and charm of the mountain scenery will continue to be a potent factor to the same end. And it is confidently predicted that before another half century this State will contain one of the most densely populated and prosperous agricultural districts on the continent,

H. V. HINCKLEY, M. Am. Soc. C. E.—During the past nine years I have observed irrigation in Central and Southern Colorado and Southwestern Kansas. To ask whether irrigation is a success is to ask whether it is profitable to pay from one dollar to two dollars per acre to insure a full crop in place of one-half or two-thirds of a crop, or sometimes no crop at all. Of course the irrigating privilege per acre may be abused, and too much water is no better than too little. The amount of water and manner of application to produce the best results is a matter to be learned only by experience in each particular case. It is a wonder to my mind that irrigation has not been more extensively practiced in the United States. The first irrigating canal in Kansas was dug in 1880. There are now not less than seven main canals in operation in Southwestern Kansas along the Arkansas River, aggregating possibly three hundred miles in length. A new canal (the Eureka) is just completed from Ingalls, *via* Dodge City, to Kinsley, a distance of 70 miles. The laterals or branches will have several times that mileage. The main canal is 40 feet wide, falls 1½ feet per mile, carries 8 feet of water, has cost about eight hundred thousand dollars, and its irrigable territory embraces at least a half million acres of land that now raises nothing for want of water. The average rain-fall is 19 inches, being mostly out of season and unreliable for crops.

The Arkansas River in Kansas is nearly or quite dry during the fall and winter, but through the summer, when water is needed for irrigation, the storms and melting snow on the "Snowy Range" of Colorado swell the river to a turbulent stream.

I quote the following: "Careful estimate of the average of crops grown by irrigation in Western Kansas: Irish potatoes, 300 bushels per

acres; sweet potatoes, 300 bushels per acre; onions, 400 bushels per acre; cabbages, 4 000 heads; melons, 8 000; turnips, 1 000 bushels; oats, 75 bushels per acre; spring wheat, 20 to 25 bushels per acre; corn, 40 bushels; sorghum, 15 tons; millet, 4 tons; alfalfa, 8 to 10 tons."

In Kansas "it shall be unlawful for any person or corporation to locate or construct any irrigating canal along or upon any stream of water, or to take and use the water of any stream in such a manner as to interfere with or in any wise hinder, delay or injure any milling or irrigating improvements already constructed or located along or upon any stream of water, or to diminish the supply of water flowing through any established irrigating canal."

A corporation for irrigating purposes, organized under the general laws of the State, acquires a perpetual right to take water from a natural stream, subject to the above limitation. In Colorado the canals upon any stream share the water *pro rata* under the direction of water commissioners and under the general supervision of the State Engineer.

I have seen people wild over their first experiences at irrigation, and I have seen land appreciate wildly from $5 per acre to $200 on the advent of a canal and afterward fall to $20 or $30 per acre where it belonged. Land where full crops cannot be raised with an annual certainty is permanently increased in value by irrigating facilities.

FREDERICK EATON, M. Am. Soc. C. E.—The following practical illustrations in support of the claims for the benefits of irrigation are based on experience and personal knowledge.

The Colony Riverside, of San Bernardino County, Southern California, comprises about six thousand acres of land.

It depends entirely for its success on irrigation, like the largest part of the southern part of our State. The soil of the colony is a sandy loam, moderately heavy and of a brown color, caused by oxide of iron; the stratum is eight to twenty feet deep, and rests on a stratum of sandy gravel. The climate is well adapted to the culture of the great majority of fruits.

These lands, before they were settled, were not even considered suitable for grazing purposes, as the average annual rain-fall did not exceed four inches; in consequence the wild grasses seldom attained a growth that would furnish picking for sheep. The lands at that time had therefore hardly any value.

When these lands were put under irrigation some fourteen years ago, they sold for about twenty-five dollars per acre. They have since been steadily advancing.

We find them changing hands now at three and four hundred dollars per acre for uncultivated lands, and from eight to fifteen hundred dollars per acre for lands with matured vines and trees. It cannot be justly charged that these prices are stimulated by social, educational and other such advantages, while the products net the land-owners, annually, two hundred dollars per acre. As further evidence that these prices are entirely due to the influence of irrigation, I will state that a tract in the immediate vicinity of Riverside, having the same character of soil, has recently been made available for cultivation by the construction of the Gage Canal, and the lands which were bought for about ten dollars per acre before the canal was built, are now selling for one hundred and fifty to three hundred dollars.

This land has the same communication facilities and markets as Riverside, and as there are no improvements on them yet, there is nothing but the water to which this increase can be attributed. If the water apportionment to these lands were made on the basis of duty obtained under the Riverside Canal system, the lands would sell for fifty per cent. more. The duty expected from a cubic foot per second under the Gage Canal is two hundred and fifty acres, which is about seventy-five acres more than has been realized under the Riverside Canal. It is possible to obtain this duty for such crops for which the land is intended to be used, provided the distribution is effected through pipes extending over every carrier. This system of distribution would add about fifty dollars per acre to the cost of the land.

Water rights are sold in the Gage Canal at the rate of twenty-five thousand dollars per cubic foot per second, which, on the proposed duty basis, makes the water right for each acre one hundred dollars. The land without a water right is worth ten dollars per acre, and immediately rises to two hundred dollars or more when the water right has been appropriated to it. These figures indicate that land originally worth one thousand dollars, by an investment of twenty-five thousand dollars, became worth fifty thousand dollars. As to the probability of an appreciation in these values, there can be no question so long as the water supply holds out. The experience of Riverside would seem to decide this point.

As to the permanency of the values, it remains with the orange and raisin market to determine.

The foregoing illustration is one in which the argument in favor of irrigation is conclusive. I will produce another where the proof is less striking, but still very clear.

Pasadena, a settlement situated in one of the valleys of Los Angeles County, has an average annual rainfall of about fourteen inches. The peculiarities of the soil are such as to retain moisture well, and the locality is frequently visited by moist fogs. The water supply is very limited, and the most rigid economy is practiced in its distribution.

The duty obtained from a cubic foot per second has been reported as fifteen hundred acres. In order to accomplish this, the entire distribution is done through iron pipes, laid largely in such a manner as to enable the water to be delivered through a hose at each tree. The method of preparing the ground for irrigation, as practiced in this section, and all others where water is scarce, is to hoe up a levee around the tree about six inches high so as to form a basin about eight feet in diameter. This basin is filled with water to the depth of about six inches. A constant discharge of a cubic foot per second will fill 150 000 of these basins eight times a year, which is equal to a flow of four feet over the area occupied by each basin, or a flow of six inches over the entire surface of fifteen hundred acres. This basin system of irrigation is attended with bad results and should never be started. It concentrates the roots around the trunk of the tree, and forces their growth to the surface. The practice of Riverside, and other places where water is plentiful, is to flow between the trees in furrows. This method requires three times the quantity of water used by the basins, but it is the most approved way. There are many improved places in the Pasadena settlement which have never been irrigated, but they do not produce in quantity what the irrigated places produce. It is claimed by those who have no water rights that cultivation is a substitute for irrigation and gives the same results.

This is true in this section as to the "growth," but will not hold in regard to the "yield."

In conclusion, I will say that irrigation will, in every instance, prove beneficial to every part of Southern California.

HENRY A. BRAINARD, M. Am. Soc. C. E.—There is no question about

the fact that irrigation has changed the deserts of California and Colorado into fertile fields, and that from being almost worthless they are now worth several hundred dollars per acre in many localities. The land about the thriving City of Los Angeles was little better than a desert, and a tract of land near the town of Riverside, purchased for a few dollars per acre three years ago, and being now supplied with only a very moderate portion of water, is valued at $300 per acre.

Some lands in California seem better adapted to endure the long months of rainless summer than others. On such lands a growth of wild oats springs up in winter, and becomes ripe and dry in June. On desert lands sage brush and cactus are indications of its arid nature.

In what I have to say upon irrigation I will endeavor to confine myself to two subjects which I see are not treated in Mr. Dorsey's paper.

First.—Irrigation by means of artesian wells; and

Second.—The circumstances and conditions when irrigation is detrimental.

I have observed irrigation by artesian wells in a section of country of triangular shape, the base being the southern end of San Francisco Bay, and the apex a point a few miles south of the the City of San José. Within this district artesian water rises from two to twenty feet above the surface. The wells are from four to seven inches in diameter, cased with iron and capped at the top, with regulating stop-cocks or valves by which the supply may be entirely shut off.

Surrounding this district is still another, in which water rises to the surface only, or within distances down to 50 or 60 feet, the wells being from 100 to 200 feet deep.

In the artesian belt the wells vary from 100 to 500 feet. One well irrigates from ten to twenty-five acres of land. The wells are bored along the highest side of the land, the overflowing water being conducted in wooden flumes laterally, and distributed as in any irrigation.

A system of sub-surface irrigation has been attempted by covered perforated pipes, but I have never observed a case of three years' standing that was not a failure; roots fill the pipes, and it is soon abandoned. If it could be used it is more economical of water.

The crops benefited by irrigation are strawberries, small fruits, garden vegetables, garden seeds, alfalfa (for hay and pasture), and late sowed or second-crop fodder corn, which is put in after a crop of barley has been harvested. By means of irrigation we harvest strawberries in

April, and thence every month till January. As I write (December 23d) our markets are plentifully supplied with them for Christmas.

In the district where water does not flow, pumps are used, driven by steam or horse, wherever irrigation is desired. A small engine will irrigate five acres in twenty-four hours, and on the basis of once a week in the application of water, will have a capacity of thirty-five acres.

The advantages of irrigation by artesian wells are: Absolute control of the water as to the amount and also as to the time when it may be used. No complication of riparian rights and appropriation can arise; you use your water when you need it, and just as much as your wells can supply. As artesian wells have multiplied, there has been a reduction of head amounting to from two to four feet within the last twelve years.

Second.—In speaking of the disadvantages of irrigation, I will say that in the valley pastures of Santa Clara County, which I shall use as one location where I have made observations, there is an average rainfall of 12 to 14 inches (21.75 last winter); on the Santa Cruz Mountains, next the ocean, from 40 to 60 inches; and in the coast range proper, on the east side of the valley, 24 to 40 inches. Streams run down from the mountains and sink after the month of June, except the Coyote and Guadalupe Creeks, which carry a small stream during most seasons. Rain falls from November to May inclusive, and there are five months of rainless summer.

This county is largely planted to orchards and vineyards; what is not so occupied is used for grain and hay (hay here consists of grain cut before it is fully ripe). Irrigation has been tried on orchards and vineyards, and is being entirely abandoned by most people.

Grain does not require irrigation. Sowed during winter it ripens in June. Trees grow more rapidly and keep greener for a longer season by irrigation, but they fail sooner. Irrigation causes them to throw out roots near the surface, and they are not well fitted to endure a drouth. Trees never irrigated send their roots downward for moisture, and do not suffer. Fruits raised on irrigated trees grow larger than non-irrigated fruits, but lack in flavor and solidity. Irrigated fruits will not bear transportation; non-irrigated fruits stand transportation to Chicago or New York.

A large crop here consists of French prunes. On irrigated trees four pounds of fresh prunes are required to make one pound of dried ones,

while from trees not irrigated two and one-half pounds of fresh fruit make a pound of the dried article, which is better than that from irrigated fruit. The same thing in regard to peaches. Irrigation makes them larger, but watery and flavorless; canners do not like to buy irrigated fruit of any kind, and it is almost worthless for the evaporater. It has been supposed that oranges must be irrigated. One of the best groves I ever saw never had one drop of irrigation, and bears abundant crops.

Vineyards that are irrigated produce grapes that make a poor, crude wine. Table grapes that are irrigated do better, but they will not bear transportation to distant markets. There is ample proof of this. Grapes from the irrigated vineyards of Southern California do not keep half as long as the grapes raised on the foot-hills of Central California. The latter go successfully to New York; the irrigated fruit in most cases proves a loss.

Thorough cultivation, stirring the surface soil, takes the place of irrigation. If the surface for three or four inches is kept stirred and pulverized, there is a capillary attraction that brings the water from the depths, and moisture comes from below instead of from above, as in irrigation.

Another ill-effect of irrigation is malaria, which almost always results from its operations.

In the San Joaquin Valley, and southward, there are many places, formerly healthy, where people now suffer severely from chills and fever and other forms of malarial diseases. These are unknown when irrigation is not followed.

Recognizing the benefits of irrigation to desert lands and to the crops we have heretofore named, we should recommend to every engineer to study carefully the rain-fall and soil of any country before undertaking or advising expensive works for irrigation. If there is an annual rain-fall of ten or twelve inches, irrigation should only be provided for the products heretofore named, leaving grain, fruit and vines, squashes, melons and trees to be provided for by cultivation.

We know of many places where thousands of dollars have been expended for irrigation, and the works finally abandoned as not desirable. We have seen as many dry fields, producing in their natural state nothing but chemisal and sage, and formerly considered dry and worthless, reclaimed by cultivation only, and made to produce grapes and fruits in

abundance, and rising in value in four years from $10 to $400 per acre.

C. L. STEVENSON, C. E.—In Utah, with an annual rain-fall averaging less than sixteen inches, and which rainfall almost entirely occurs between the 1st of November and the latter part of May, irrigation is absolutely essential to the raising of nearly all the products which go to support life.

Lying in the great basin between the Sierra Nevada and Sierra Madre, are those agricultural valleys and mountain slopes which have become noted for their continued fertility over a period of some forty years.

The alluvial deposits there found, both in valley and on mountain-side originally only growing sage brush and wild grasses, are now being gradually redeemed. with a result that would seem incredible to any not accustomed to the effects produced by the proper application of water.

In this connection I would say that my statement to Mr. Dorsey, that with proper irrigation a failure of crops is unknown, and which he cites as strong language (although my experience for twenty years), is simply one of those statement of facts which would with us in Utah excite no comment.

When some forty years ago Brigham Young and his followers entered the Great Salt Lake and Jordan Valleys, they were told by Bridger, one of the earlier pioneers, that he would give a twenty-dollar gold piece for every bushel of wheat they could raise; it was probably a surprise to both when on the very ground pointed out, fifty-six bushels of wheat were raised to an acre under the crudest methods of applying the waters of the nearest mountain stream.

Even to-day the system of irrigating in Utah (if system it can be called) is of the crudest, with some trifling exceptions.

Unlike some of the adjoining Territories, the custom in Utah has obtained of having the use of "appropriated" waters inure to the land in perpetuity. That is, a small community would take up the entire flow of a stream and accord it to a certain acreage without regard to the real water requirement per acre. This generally was done under the auspices of the Mormon Church, the dominant element then and now in Utah, or rather of the leading men therein.

When other settlers came in to occupy adjoining lands, they found

themselves only entitled to "waste water" or a lawsuit. Hence has arisen the singular fact of adjacent lands having first, second and third water rights. Those with first right, say in Jordan Valley, from original cost of $1.25 per acre, at once attained a value of from $15 to $25 per acre, and inside of five years a value of $80 to $100. This last is a small valuation, when we consider the sale value of the crops that can be raised thereon with so little cost to the cultivator.

The waters of irrigation from the mountains annually carry with them fresh fertilizing material, so that practically it costs the average Utah farmer less to keep up his ditches and apply his waters of irrigation than it does the Eastern farmer to manure his land.

One field near Farminton, at first producing some sixty bushels per acre, was kept in wheat for thirty years with no other fertilizer than what was brought by the waters, and there was after the second or third year a general average yield of over forty bushels to the acre.

Not only does the "water right" immediately increase the value of the land to which it attains, but it enhances values to land adjoining, even if such land has no water right.

In Utah, as elsewhere, it is found that proper irrigation tends to a permanent improvement of the soil, and substantially an increasing value more than commensurate with increasing population; at least this is the fact with us in Utah.

Somewhere about the year 1880, Mr. O. J. Hollister, a very careful statistician, and others, as well as myself, made pretty careful investigations as to the "duty" of a cubic foot of water per second when applied in the ordinary way—and right here let me state that the average farmer soon learns not to use an excess of water on his crops, however much he may let run to waste to prevent a "second right" neighbor from getting it. Since then I have verified, in several ways, the results then obtained, and can safely say that while this duty averages one hundred acres, at least one hundred and twenty acres could be just as well cultivated with the same amount of water.

For the first few years, according to soil, the area that can be successfully cultivated with one cubic foot of water per second will not exceed, perhaps, sixty acres, but as the grounds become saturated, the average soon, with us, gets to be about one hundred acres.

I do not think the Utah method of having the water right made a part of the realty by any means a correct one, since it naturally leads to

a less acreage cultivated. For the best interests of the community, I consider that the water used for irrigation should be paid for by the cubic foot, delivered to the consumer.

Owing to lack of proper system of distribution and an almost total disregard of engineering economy in construction, I think it safe to say that not one-sixth of the available waters now appropriated is really utilized in Utah.

E. E. RUSSELL TRATMAN, Jun. Am. Soc. C. E.—In connection with the paper and discussion on "Irrigation," the following extracts from "Irrigation in Spain," written by J. P. Roberts, and published in 1867, may be of interest.

"In some of the immense plains which form the valleys of Spanish rivers, the soil, which is a rich, black, alluvial deposit, is often from 10 to 20 feet in depth; and when the surface becomes exhausted, the farmer replenishes it by digging trenches and turning up the virgin earth, and thus, year after year, crops are grown without putting any manure on the land. When these valleys are irrigated, there seems to be scarcely any limit to what they can produce.

"One cannot but feel surprised at the large amounts which were expended in years past in irrigating comparatively small plains. The Alcavadre Vega, in the valley of the River Ebro (which contains only about three hundred statute acres), is watered by a noria, or undershot wheel worked by the river, and from a careful estimate it has been found that the works for irrigating this land must have cost at the rate of about $175 per acre. This is a great outlay, when the quantity of water pumped up, which is only twelve gallons per minute, is taken into consideration.

"In the Rioja district there are some highly cultivated valleys, which are irrigated in various ways by the waters of the Ebro and other rivers, and they are so much prized by their owners that it is very seldom a plot of ground is to be sold. In the Alcavadre plain the statute acre sells for about $625 to $750, and in other districts which are watered by the rivers Najarilla, Yregua and Ebro, land is rented at from $46.25 to $50.50 per statute acre, while the same quantity of dry land in these districts only produce an annual rent of from $2.16 to $2.88. A report on the effects of irrigation on land adjoining Logrono states as follows: 'The crops are insecure in consequence of the dryness of the climate, and third-class land only produces $2.16 worth of corn to each half acre

(.47) of land. This is at the rate of $1.08 per year, for it is the custom of farmers to till the land only once in every two years, and even this small return is uncertain for want of water. If these lands were irrigated, the produce would increase from half an acre to three and a-half acres of corn for each acre of land, calculating only one crop for every two years; but with the benefit of irrigation the lowest estimate would be one crop for each year, and with good management you could safely calculate on two crops annually, even on third-class land.'

"In the Province of Zamora, in the valley of a river, a part of which was partially irrigated, the watered land sold at from $175 to $205 per acre, while the dry land usually realized from $70 to $90. The difference between the value of watered and unwatered land is not so great there as in other parts of Spain, owing, in some measure, to the climate and want of experience in irrigation, but chiefly to the ignorance and indolence of the farming classes.

"A Spanish engineer who has given considerable attention to the subject of irrigation (Don Juan de Ribera), states that a good supply of water increases the value of land near Madrid from four to ten-fold, and he thus classifies it:

First-class unwatered land, worth $160 per acre, increases to $640 when irrigated.

Second-class, worth $100 per acre, increases to $500 when irrigated.

Third-class, worth $60 per acre, increases to $360 when irrigated.

Fourth-class, worth $30 per acre, increases to $300 when irrigated.

"In the Ampurdan, a fertile plain on the shore of the Mediterranean, the farmers state that the value of land is increased from 100 to 200 per cent. by irrigation. In this valley, which is in the highest state of cultivation and is thickly populated, the best unwatered land sells at from $500 to $600 per statute acre. The climate is hot and dry, but as the land is low, being only a few feet above the level of the sea, the unirrigated ground retains the moisture and often produces abundant crops, though of course much depends on the quantity of rain which falls during the winter and spring. The only part that is properly watered is a large government model farm, and it would be impossible to see more luxuriant crops than those grown on that estate. Although the supply of water is small, it is sufficient to show what the benefits of

irrigation are on such rich land. In the valley of the River Tagus it is said that the produce from irrigated land is twelve times greater than that from dry land.

"It may be laid down as a rule that the increase in the value of land consequent upon irrigation is always in proportion to its quality, for while first-class land may be increased one or two-fold, the worst description of Spanish desert, on which goats and sheep wander in quest of a mouthful of herbage, may be brought to produce abundant crops of corn, and thus increase in value from 1 000 to 1 500 per cent.

"The most general and effective system of irrigating is by constructing a weir across the river, and cutting a main canal, with numerous branches or channels for distributing the water. Most Spanish rivers fall rapidly, and as canals are usually made with a very slight grade, they soon get away from the rivers and attain a sufficiently high level to command the plains which it is intended to irrigate. It is not unusual, in cases where rivers have a quick flow, to construct a canal without a weir, commencing above a rapid where the stream is dammed up by some natural obstruction. From the River Ebro, which has a fall of about 1½ per 1 000, several canals have been made in this manner.

"Along the banks of this river numerous norias are in use for watering gardens; they are roughly constructed undershot wheels, with small buckets attached for lifting the water, and are usually manufactured by country carpenters at a cost of from $1 250 to $1 500 each. The expense is very considerable and quite out of proportion to the quantity of land irrigated, which seldom exceeds from 200 to 300 acres. These norias are entirely wrong in principle, for they raise the water from the tail-race of the weir instead of from its head, thereby uselessly wasting power. One of these weirs, which must have cost (including the weir, etc.), at least $30 000, with over 100 H. P. only lifted 11 gallons per minute to a height of 16 feet, which is less than one man could pump up in the same time. The weir was constructed of large blocks of stone piled closely together, and forty-two per cent. of the water in the river passed through, not over it. Small norias worked by horses, for lifting water from wells to irrigate gardens, are much in use all over Spain; many of them are just the same as those used by the Egyptians, being a roughly made timber-wheel with an endless band on which numerous earthenware vessels are fastened; the band is sufficiently long to allow the pots to fill themselves in the well, and they are discharged above

when passing over the wheel into timber conduits which lead the water to small reservoirs; these tanks are often half filled with stable manure, and the water is allowed to lie on it for hours before it is used, by which means it not only refreshes but also manures the land. Several well-constructed iron norias have been erected and considerable quantities of water are raised in this manner. Windmills are occasionaly used to work pumps, and water is often lifted from wells by means of a long pole suspended to a tree with a rope and bucket on one end and a counterpoise weight on the other. One of the oldest systems of irrigation was that of collecting the rain-water in large reservoirs formed in the mountain districts.

"The most important canal is the Imperial Canal, which was originally intended for navigation only, but is now almost exclusively used for irrigation, as it waters an immense tract of country near Saragossa; the weir at Tudela is a splendid specimen of masonry, and is a great monument to the talent and perseverance of the priest-engineer, Don Ramon de Lignatelli, who designed and carried out the whole work. It was originally intended to carry this canal to near Caspé, where it was again to unite with the Ebro, but it was completed only as far as Saragossa, from which point a small conduit of more modern date has been made for irrigation alone; this latter is 22.32 miles long, and carries about 70.6 cubic feet of water per second.

"The author records two failures of works constructed during the present century—one where the engineer commenced his canal at a point in the river below the level of the plane to be irrigated, the mistake not being discovered until a considerable part of the canal had been made and several thousand dollars wasted. In the second case the engineer made a mistake, and after about $150 000 had been expended, it was found that the level of the canal was too high, and the water refused to enter it.

"The Urgel Canal, in the province of Lerida, taking its water from the River Segre, was carried out by a Spanish company under a royal concession authorizing them to collect ten per cent. of the produce of the valley in payment for the water. As this system did not work well in practice, the company made arrangements with the proprietors for a payment of $4.62 per acre per annum. The canal irrigates an immense extent of country, and the government contributed considerable subsidies towards its construction.

"At the date of publication (1867) an English company was engaged in constructing two large and important canals, the Henares Canal and Esla Canal. The former required some heavy works, including a large weir and a tunnel about four thousand feet long. The weir is 16.4 feet high and 426 feet long. It rests on a rock foundation, and the interior in of concrete. The first section, 10.5 miles long, irrigating twelve thousand acres, had just been opened, and the total length was to be twenty-nine miles. The latter passes through a flat country, and was nearly completed. The engineers of these canals were Mr. Bateman, of London, and Mr. Higgins, of Madrid.

"Many concessions had been applied for, as no canal taking more than one hundred liters of water per second can be made without a royal concession. These concessions are expensive to obtain, and about two years are generally required to secure one. The period is for ninety-nine years, at the expiration of which the canal becomes the property of the government or land proprietors. The mill falls belong to the canal company in perpetuity. Subsidies of about fifteen per cent. on an estimate certified by government engineers, are occasionally granted, and are paid in three parts: 1, when the earthwork is finished; 2, when the bridges, culverts, etc., are completed; and 3, when irrigation is commenced.

"The weirs for canals and norias on the Ebro are usually from 6 to 9 feet high, constructed roughly of large blocks thrown loosely together; often as much as 40 or 50 per cent. of the water filters through them, In the small rivers the weirs are formed by driving two rows of small piles and filling the space between them with brushwood, sods and stone. Considerable quantities of water run to waste below the weirs, even if they are well constructed, the water finding its way under the weirs through the boulders that form the beds of all the rivers which have rapid falls. The foundations of new weirs are carried down to bed rock or impermeable clay. The canals in the Rioja always follow the contour of the country, utterly regardless of the radius or shape of the curves, but as the fall is very slight the velocity is small. The side slopes are often less than ½ to 1, but stand very well. In every valley in the Rioja a different tariff of water rates is found, as they are arranged according to the expense of the conservation of the canal, etc. The meter in use is usually a flat stone with a round hole, through which the water passes, and so much per hour is charged for the stream, regardless of the head of water in the canal or tank. In the flat plains a

small embankment of clay is formed around each field, and when irrigation is required the water is admitted from some of the minor channels through an opening in the bank, usually at the corner of the field, and allowed to flow till the inclosure is covered to a depth of about three inches. On sloping ground the field is usually leveled into a series of horizontal plots, each irrigated as above, or else small cuts and mounds are made on the slope at right angles to the flow of water to check its velocity.

"All the old weirs cross the rivers obliquely, in some cases at an angle of 45 degrees with the bank. Some of the modern canals leave the river nearly at right angles, but the results have not been satisfactory, a dead point occurring at the inside of the curve which the water takes to enter the canal, and this point silts up and causes a bank which gradually blocks the canal.

"While in the north of France, and in some parts of England, large quantities of water are allowed to flow over the fields, the principal object being to manure the land by the sediment thus deposited, in Spain irrigation is only used to moisten the ground and to supply the want of rain; so that a quantity of water which would be considered insufficient in other countries would more than satisfy the wants of a Spanish farmer. Much of course depends on the climate, the soil, and the crops. Corn and olives are usually irrigated from four to six times a year, and fruit, vegetables and green crops are watered at least once a week during the summer and autumn months. Where the supply of water is abundant the farmers irrigate in a slovenly and wasteful manner, while in districts where a little has to go a long way not a drop is allowed to run to waste. In Valencia the average quantity of water used is 1.33 gallons per minute per acre, which is equal to 11.2 irrigations per year. The author is of opinion that the proper average quantity of water for vegetables and green crops is .75 liter. New canals to irrigate small plains are usually constructed to carry 5.34 gallons per minute to each acre, it being assumed that in course of time the whole valley will be laid under cultivation. It would of course be impossible to give such a supply on a very large scale, and where an immense district is to be watered the canals are made to carry one-fourth to one-half that quantity, the amount being regulated by the total volume of water in the river from which the canal is to be supplied.

"The following table shows the quantities of water authorized for new (1867) canals by royal concession:

Canal.	Quantity of water per minute to each acre.	Land to be irrigated.
	Gallons.	Acres.
Cinco Villas	1.3	123 550
Tamarite	1.6	256 984
Henares	2.2	30 381
Esla	3.2	22 724
Tajo	5.0	8 150
Ebro	5.3	6 422
Isabel II	4.0	4 446

"In the Rioja the irrigation is according to the weather and the crops. When there is a fair amount of rain four irrigations are given to corn, flax, potatoes, olives and vines; in dry seasons six or eight irrigations. Garden vegetables are watered every week from May to October, and oftener in dry seasons, the minimum being twenty irrigations a year. This would give for

	Gallons per minute per acre.
Corn land, say 6 irrigations per year	1.41
Meadow land, 8 " " "	1.88
Gardens, 20 " " "	4.70

"The irrigation is calculated at 2¾ inches deep, but in practice they rarely give more than two inches, and often less.

"The following are the prices authorized by the concessions, the prices being per acre for each irrigation, or 154 000 gallons of water: Isabel II, 40 cents; Esla, 38 cents; Henares, 56 cents; Logroño, 50 cents. In Malaga the water rent per annum averages about $4.56 per acre; on the Lobrigat canals from $1.32 to $4.00, and in Aragon from $1 to $6.50. In Cataluña the farmers pay for corn land, $2.88 per acre per year; for clover and artificial grass, $3.60; and for gardens, $3.84.

"The formula for calculating the size of the Isabel II Canal was $V^2 = \frac{L\,H\,I}{0.00025\,(L+2\,H)}$, but the following is considered to give more

correct results, $V = 51\sqrt{IR}$; V = velocity; I = incline; R = hydraulic mean depth. The favorite grade is from 12½ to 19 inches per mile; the best velocity is from 23½ to 27½ inches per second, as that prevents silting and growth of weeds, but does not scour the channel. For such velocities a Spanish engineer states that the radii of curves not protected by pitching should not exceed 492 feet, with a minimum of 328 feet; if pitched, the radius may be reduced to 65 feet. Some of the old canals, with very slight grades, have unpitched curves of 16.5 feet radius.

"In the Rioja the main canals are cleared out once a year, the water being turned off to allow the laborers to work freely. Most of the old canals have large deposits of sediment and growths of weeds. This annual cleaning out costs from $40 to $80 per mile. The cost per acre for irrigating land is estimated at from $30 to $42, according to locality and circumstances; in the case of a canal to be lined with brick the estimate was about $75.

"By the Water Act of 1866, all foreign capital invested in irrigation canals or works is under the protection of the government, and cannot be confiscated in time of war; the minority in a newly irrigated valley must either irrigate or sell the land to the canal company, and under this law the proprietor can, if his demand be exorbitant, be compelled to sell his property; the amount being decided by capitalizing the annual land tax paid to the government and augmenting the product fifty per cent."

Mr. JOHN WESTCOTT (formerly Surveyor-General of Florida).—In Florida, on the peninsula, where there is a well-defined land and sea breeze, and rainy and dry season, drainage first, and then the artificial application of water, adjustable at the proper time and supplied in such quantities as is necessary in the dry season to every branch of agriculture, is cheap, advisable, and profitable. There is hardly a 40-acre lot in Florida where the flat land has not fall enough to take the water off as fast as it falls by constructing at small expense sufficient drains in the rainy season, and artesian wells can be bored from 60 to 250 feet. They will supply any amount of water desired, and so completely under control, that a supply in the dry season can be adjusted in accordance with the natural demand for extensive farming and farm gardening.

Artesian wells can be bored from 2 inches to 12 inches in diameter,

flowing any amount of water desired to be conveyed into ditches or furrows, where a rich, teeming soil will soon take it up without causing improper scalding by overflow.

Pine-apples thus cultivated can be forced to weigh from 8 to 15 pounds each. Bananas, tomatoes, onions, potatoes, and most other commercial vegetables, by a proper supply of plant-food and necessary adjustable supply of water in the dry season, can be made to yield a crop several folds greater than with ordinary cultivation.

This is not fancy; it has been done, and can again be accomplished.

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(Vol. XVI.—March, 1887.)

A WATER-METER FOR IRRIGATION.

By A. D. FOOTE, M. Am. Soc. C. E.

READ OCTOBER 6TH, 1886.

Engineers of irrigating works have long felt the want of a cheap, practical and reasonably accurate method of measuring small volumes of flowing water as delivered to the irrigator.

Selling or dividing water by the acre or area irrigated offers very great inducements for waste, and has many other serious disadvantages.

Selling or dividing water by the methods of measurement now in use causes more vexation and dissatisfaction, to say nothing of legal entanglements and expenses, than all the other work of an irrigating enterprise.

The company by which I am employed proposed to furnish and distribute the water required for irrigating about six hundred thousand acres of land. The legal advisers of the company strenuously opposed selling water by the acre irrigated. They urged (and their long experience in irrigation litigation gave great weight to their opinion) that every settler upon the land would become seriously dissatisfied, and it would be a constant menace to the company to have such a great community with a common cause of complaint against it.

It therefore seemed absolutely necessary for the company to adopt some method of selling water by a measured quantity, and at a certain regular price per unit of that quantity.

The miner's inch is the usual unit of water measurement in this locality, and by custom, and partly by statute, the "4-inch" miner's inch is the particular kind used.

It purports to be the quantity of water which will flow through an inch square orifice in an inch board with a head or pressure of four inches above the center of the orifice, but is in reality the quantity

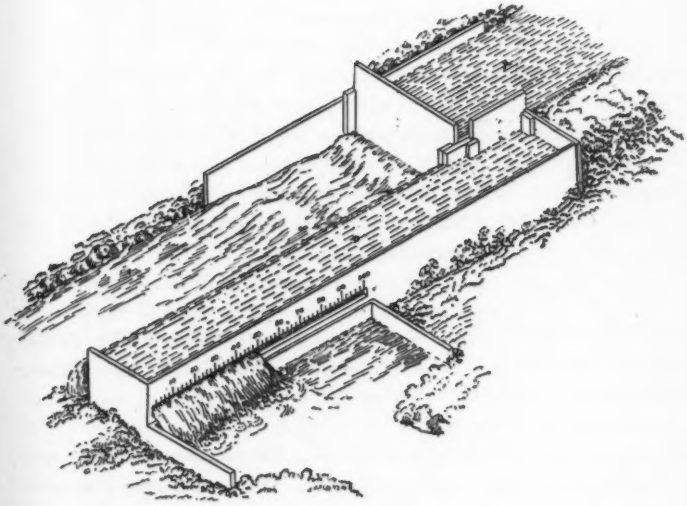

PLATE XV.

of water which will flow though an inch square orifice in an inch board with a head or pressure depending upon the care used in adjusting the gate which admits the water to the orifice, and on the fluctuations there may be in the volume of water flowing in the channel conducting the water to this gate.

It has been described as a "nondescript inch which can scarcely be credited with a remote approximation to correct measurement."

It is called unscientific, inaccurate, unsatisfactory to both seller and buyer of water; and yet it is the best and almost only method used in

the whole Western part of our country for measuring flowing water in small quantities. In some parts of Colorado a so-called "head" is used, but it is no more accurate than the inch, and not as convenient.

After much consideration it seemed to me that the miner's inch, although so much derided by engineers, had many valuable qualities. One theoretical inch, as above described, delivers 1 800 cubic feet of water in twenty-four hours. Forty-eight of them equal one cubic foot per second, therefore easily translated into scientific or standard terms. It is small enough not to require subdivision, which is a great convenience.

Last May I constructed a water-meter for measuring 4-inch miner's inches, of which an isometrical sketch is shown, Plate XV. For months it has done its work in a very satisfactory manner, seldom clogging and never varying in its delivery to an appreciable amount.

The apparatus is so simple that the sketch will explain it better than words. The whole value of the meter depends upon the long weir, perhaps better described as an excess or returning weir, which returns all excess of water in the box back to the ditch and thus keeps the pressure at the delivery orifice practically uniform.

I am well aware that the measurement is not absolutely accurate or uniform; but if it is remembered that the variation in delivery is only as the square root of the variation in head, and that, owing to the long excess weir the variation in head is only a small portion of the variation in the delivery ditch, it will be seen that actual delivery through the orifice is very nearly uniform.

There need be but an inch or two loss of grade in the ditch, as but very little more water should be stopped than is delivered through the orifice.

The gate or other obstruction in the ditch should back the water sufficiently to keep the excess weir clear, and at the same time keep say a quarter of an inch of water on its crest, and the surface of the water in the box should then be exactly four inches above the center of the delivering orifice.

The principle of the long excess weir can be used, of course, for delivering water through an open notch or weir, but it is more accurate with a pressure or head, and the greater the head the greater the accuracy, as will readily be seen.

Any one using the meter will naturally adapt it to their own circum-

stances and desires. It is cheaply constructed and easily placed in position, costing from four to six dollars; quickly adjusted, as the gates do not have to be precisely set; needs no oversight or supervision (if properly locked as they should be) until a change in volume is desired; will deliver a large or small quantity, which is a great convenience, as the irrigator usually wants a small stream continuously and a large stream on irrigating days; is not likely to clog, as floating leaves and grass pass over the excess weir. Half-sunken leaves may catch in the orifice, but as it is to the farmer's interest to keep that clear, he will probably attend to it.

To me, however, the greatest merit which the method possesses (excepting its accuracy) is that the irrigator himself with his pocket-rule can at any time demonstrate to his entire satisfaction that he is getting the full amount of water he is paying for.

I have no patent on this invention, and if any Members of the Society will try the meter and become as well satisfied with it as I am, I shall be amply repaid for placing the design before them. I would like however to have their opinions of it in any case.

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356.
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SOME CONSTANTS OF STRUCTURAL STEEL.

By PALMER C. RICKETTS, Assoc. Am. Soc. C. E.
READ JUNE 2D, 1886.

The comparatively meager existing data with regard to some of the constants of the structural steel made at present in this country, especially that referring to the coefficient of elasticity in compression, caused the writer to undertake some months ago a series of tests on that metal varying in carbon from $\frac{8}{100}$ to $\frac{40}{100}$ of one per cent. It was determined to compare the coefficients of elasticity in tension and compression in adjacent pieces from the same bar, and at the same time to find, when possible, the variation in resistance of specimens from the ends and centers of rods of considerable length, thus determining the homogeneity of the material used. The carbon was also found by the color test from drillings at each of these three places. For these determinations in the Bessemer bars I am indebted to Mr. John M. Sherrerd, the chemist of the Troy Steel and Iron Company. The shearing resistance of the metal was also found, and the ratio between its resistance in double and single shear calculated. On account of the capacity of the 50 000 pounds Olsen testing machine used, and also because a great part of the tests of structural material is made on specimens of about half a square inch in section, the pieces tested were take from three-quarter inch round rods. These bars were in no case turned down, but were tested with the "skin" on. For the Bessemer rods, selected at different times from the stock of the Troy Steel and Iron Company, I take pleasure

in thanking Captain R. W. Hunt, M. Am. Soc. C. E., its manager, and for the fifty open-hearth rods, numbered from 1 to 50 in the tables, I am indebted to the Pennsylvania Steel Company, of Steelton, Pa. These last bars were rolled from 14-inch square ingots after several reheatings, and were 40 inches long, twelve being of rivet, twenty-four of tension, and fourteen of compression steel. They were divided into lengths of 20, 6, 2 and 12 inches, the first being used for tension, the next two for compression tests, and the last was sheared. Besides the above material, ten rods of open-hearth steel, about fifteen feet long, from metal used for the rivets of a recent steel bridge, were so cut that tension and compression pieces were obtained from each end and the center.

This was also done with the Bessemer rods of about the same length and with the single rod of "Burden's Best" wrought-iron, which was tested in order to compare the results obtained from the steel used with those from good iron under the same conditions.

The elongations corresponding to increments of stress were measured by a carefully constructed and very accurately divided instrument which reads to $\frac{1}{10000}$ inch, and on which estimations to $\frac{1}{40000}$ inch may easily be made. Through each of its two ring-shaped parts, which encircle the bar to be tested, pass three converging screws with milled heads, whose sharp-pointed ends penetrate the bar at sections whose initial distance from each other is known. Extending vertically upward from the lower ring, and diametrically opposite to each other, are two steel rods which are clamped tightly to the ring at their lower ends, and upon their tops are fitted vulcanite caps bearing insulated metal plates. These are vertically under the pointed ends of two micrometer screws which pass through projections in the upper ring. An electrical contact may thus be obtained, which becomes of great delicacy when a weak current and a sounder are used. The manner in which this instrument is supported on the bar insures the measurement of the strain in a constant distance, which was taken at 8 inches for bars in tension and 4 inches for those in compression. The strains thus measured were used in the determination of the coefficients of elasticity.

A stress of 1 000 pounds was at first put upon the bar, and the micrometer for the first time read. Readings were then taken corresponding to increments of 2 000 pounds of stress, and this was continued until the grip of the instrument upon the bar was loosened, which occurred in tension somewhat beyond the elastic limit and in

compression when the piece began to bend. The grip on the bar could be tightened at any time by means of the converging screws with milled heads, but this was not necessary until after the bar had been strained more than the amount used in finding the coefficients, and they were not touched, when once tightened, until after this strain had been reached, care being thus taken to prevent disturbance. For the sake of uniformity in comparison, the strains used in the calculations of all the coefficients were those corresponding to stresses between one and fifteen thousand pounds. This superior limit was taken after an inspection of all the results obtained, as within it the strains corresponding to successive increments of stress were essentially constant for nearly all the bars tested.

As has been stated, there are two micrometers used diametrically opposite to each other, in order to reduce as much as possible the error in strain measurements in the bar. Each micrometer being read, it is read again after an increment of stress has been applied, and the mean of the difference of the readings on each side of the bar is taken as the strain due to this applied stress. That there is bending, or at least unequal straining, is shown by the fact that these differences are seldom exactly equal, in rare cases one of them even being negative.

By dividing the means spoken of by the length in which the strain is measured, that is by eight in tension and by four in compression, there results the strains per inch. These, for the fifty bars of open-hearth steel, are given in Tables Nos. 1 and 2. As estimations to one-quarter of one ten-thousandth of an inch were made, in taking means the figures in the last two places of the decimals are found. Since the readings were first taken at 1 000 pounds, the figures first given are for the increase of stress from 1 000 to 3 000 pounds. A comparison of the strains given show them to be quite regular in each table, not only for the same but for different bars. The greatest variation in Table No. 1 occurs in No. 17, in which 0.000122 and 0.000183 are consecutive decimals. A mean of these gives 0.000152, not far from the average for this specimen. The irregularities in Table No. 2 are somewhat more pronounced, though they are not great. It is noticeable that the greatest deviation occurs in the same bar, No. 17. Here the strain for the stress between 1 000 and 3 000 pounds is 0.000215 inch. As this is the first mean, its cause might be found in a slight deviation from parallelism of the two faces of the specimen, or rather in a slight deviation of one

face from a plane surface, the faces becoming more nearly plane and parallel as the applied weight is increased.

The readings, on opposite sides of this bar, from which the mean was derived, would seem to indicate this. In fact the greater deviation from uniformity of the means in the first column than in any of the others of this table tends to show that this happened in a number of the compression pieces. In the last column is given the mean strain on the specimen per inch of length per 1 000 pounds of stress for weights between 1 000 and 15 000 pounds. The strains for three specimens from a bar of "Burden's Best" iron are also given.

Tables Nos. 3, 4 and 5 give the results of the tensile tests. The specimens were 20 inches long with the "skin" on, and were gripped at the ends by wedges in a ball and socket joint. The power was applied by hand, and the breaking was done gradually, the bars remaining in the machine from fifteen to twenty-five minutes. The same numbers belong to the same rod throughout all the tables, those from 1 to 50 belonging to the rods 40 inches long from Steelton, and the ones from 51*a* to 60*c* to the open-hearth rivet bars 15 feet long. Nos. 61*a* to 77*c* are of Bessemer metal from rods also 15 feet long.

The subscripts *a*, *b* and *c*, when attached to the same number, denote pieces from the center and end of the same bar, the letter *b* corresponding to the central piece. The specimens used for tensile and compression tests were always adjacent to each other in the rod. The classification of the open-hearth metal into rivet, tension and compression material conforms to that of the Pennsylvania Steel Company, and color tests by the chemist of that company gave the percentages of carbon and manganese shown.

The areas given throughout the tests correspond to mean diameters, four measurements at each section being taken. The average difference between the greatest and least diameters of the sections measured in the open-hearth bars was about 0.003 inch, and in the Bessemer bars about 0.010 inch, in one or two instances it being as great as 0.015 inch.

A general idea of the error to be expected, under these circumstances, on account of the use of the mean area, is given by comparing the area of an ellipse, with axes say of 0.740 and 0.750 inch, with that of a circle whose diameter is 0.745-inch. In the first case there results an area of 0.4359 square inch, and in the second case the same. If the mean of the four readings were 0.747 inch, the deviation from the ellip-

tic area would be 0.0023 square inch, and for a bar with an ultimate resistance of 30 000 pounds, the difference per square inch would be 360 pounds. The elastic limits given in tension, compression and shear were found by the action of the scale beam, because they are so found in a large majority of the tests of structural metal.

Since some of the 6-inch columns bent before the elastic limit was reached, the corresponding row of figures in Tables Nos. 6 and 7 was filled out by means of results obtained from columns 2 inches long. In these tables, Nos. 51*a* to 77*c* correspond to the long rods, and as only one short column from each one of these was tested, every third line only in this row, between these numbers, is filled. The well-known effect of carbon on tensile resistance is seen in these results; likewise the great variation in this resistance for the same carbon—a variation seen more clearly by an inspection of the following figures:

	Per cent. of carbon.	Ultimate tensile resistance of steel. Pounds per square inch.		
		Maximum.	Minimum.	Difference.
From Table No. 3.....	0.20	79 200	68 700	10 500
" " "	0.32	92 500	77 000	15 500
Report on the Bismarck Bridge—Morison	0.20	77 000	64 900	12 100
do.	0.38	98 000	78 700	19 300
do.	0.40	101 600	64 600	37 000
Report of the United States Board for Testing Iron, Steel, etc.....	0.37	100 200	69 600	30 600
do.	0.46	83 100	71 000	12 100
Report of the Naval Advisory Board—Gatewood				
NorwaySteel—So.Boston	0.14	66 400	57 000	9 400
do.	0.18	69 500	56 600	12 900
Cambria	0.18	69 700	59 000	10 700
Chester.....	0.20	73 300	58 400	14 900

Errors in determinations by the color test would account for no such differences; in fact a difference of 30 600 pounds is found in the figures above, taken from the Report of that Committee of the United States Board of which Alexander L. Holley, M. Am. Soc. C. E., was Chairman, and in this steel the carbon was determined by combustion. These figures show the inaccuracy of such statements as, "the increase in ultimate tensile resistance of steel per square inch is almost exactly 1 000

pounds for every 0.01 per cent. carbon, starting with no carbon at 45 000 pounds," and the results here found, as well as those given in the reports above referred to, and others, show the improbability of finding any relation between the ultimate tensile resistance of structural steel, and the percentage of carbon alone, sufficiently close to enable one to be inferred from the other in any particular case with reasonable accuracy. The average of the 0.09 per cent. carbon metal in Tables Nos. 3 and 4 is about 62 000 pounds; of the 0.20, 74 000 pounds; and of the 0.22, 78 000 pounds. No decided conclusions can be drawn from Table No. 3 with regard to the effect of manganese on the metal. In this table, No. 18 was from an imperfect bar with slivers on the surface. It broke at an imperfect weld with a small elongation and reduction of area. No. 47 broke at the point where the heat number was stamped upon it, and had a peculiar fracture with broad planes of shear. The numbers in the column headed Reduction of Area were obtained from measurements of the fractured area.

The variation in ultimate resistance of specimens from the center and ends of the same rod is seen from the last columns of Tables Nos. 4 and 5, the greatest being in No. 57, in which the difference between the greatest and least breaking stress is 3.8 per cent. of the least, though the average for the open-hearth rods is but 1.8, and of the Bessemer but 1.3 per cent.

There is considerable uniformity in the coefficients of elasticity as here determined. In these coefficients in compression it is believed that this is due not alone to the uniformity of the material, but also to the great care exercised in their determination. The difficulty of so confining a long piece of metal subjected to compression, that the true ratio between stress and strain, to a point near the elastic limit, can be determined, is well known. No such attempt was made, but dependence was placed upon an accurate measurement of strain within a short distance. The 6-inch columns used had their bases very carefully faced up parallel to each other. To gain room for the micrometer the specimen was placed on one of the largest faces of a hardened tool steel block $4 \times 2\frac{1}{2}$ inches by 1 inch thick, which had been planed and ground on a surface plate until its faces were smooth and parallel. This block rested on the platform of the machine, and after the column had been carefully centered a similar block was placed upon its top between it and the cross-head. When the micrometer was in place, part of it projected beyond

the ends of the column on each side of the blocks, and on account of their use the strain could be measured in four inches out of the six. No bending took place until after 15 000 pounds of stress had been recorded, and the coefficients were calculated from stresses within this limit.

From the fact that few measured strains, corresponding to consecutive equal increments of stress, are exactly equal to each other, it follows that the value of the coefficients generally change with the limit of stress taken. Thus, in Specimen No. 1,

	E Equals in	
	Tension.	Compression.
For stress between 1 000 and 15 000 pounds.....	30 602 000	30 331 000
" " " " 13 000 "	30 405 000	29 990 000
" " " " 11 000 "	30 197 000	29 767 000

Sometimes, of course, greater differences are shown. Although generally done, and done here, the uselessness of writing significant figures below the tens of thousands, and perhaps below the hundreds of thousands, place is apparent from these numbers.

In Table No. 8 is given the mean cofficients for the steels of different kinds, and also the ratio between these means in tension and compression. It will be noticed, in the first place, that these coefficients in tension and in compression do not vary much with the carbon, being practically the same for the open-hearth rivet, tension, and compression steel.

Secondly, that in tension the average is greater for the open-hearth than for the Bessemer metal by about three per cent., though in compression they are nearly the same. In the third place, that the variation in both cases is greater in the different Bessemer steels than in the open-hearth. It is also particularly noticeable that the average coefficient in tension is greater than that in compression by about 3.5 per cent. for the rivet and 4.3 per cent for the less mild open-hearth steel, and by about 1.4 per cent. for the milder and 2.3 per cent. for the harder Bessemer metal. The low ratio, 1.009, in the average of the fifty-one Bessemer specimens, is partly due to the low value of the coefficient in No. 67*c* in Table No. 5, without which the ratio is 1.014. This piece stretched abnormally, the strain per inch between 5000 and 7 000

pounds being 0.000400 inch. Assistant Naval Constructor Gatewood, in the report of the Naval Advisory Board on the mild steel for the new cruisers, remarks that

"The modulus of elasticity of mild steel in compression is generally taken the same as for tension. This was very closely true in some tests of shaft steel recently made on the Emery machine at the Watertown Arsenal for this Board."

He does not give these results, but further adds:

"Mr. James Christie, from some recent experiments on Bessemer steel of structural quality, gives the value of the modulus under compression much less than under tension. Thus for 0.12 carbon steel he obtained for E in tension 27 030 000 to 32 780 000, with an average value of 30 135 000, while for compression the values were 15 132 000 to 24 490 000, with an average of 20 478 000. This result is anomalous and should be very carefully verified before being accepted."

These figures of Mr. James Christie, M. Am. Soc. C. E., are to be found in Vol. XIII of the Transactions of this Society, and he further there gives as a mean coefficient in tension for 0.36 carbon steel 29 280 000, and in compression 24 570 000.

The coefficients in compression found in this paper are not so small, but the results tend decidedly to show that they are smaller than those in tension. In the open-hearth steel they are larger but in two cases out of the eighty, in No. 12 and in No. 53c. In No. 12 the tension piece was slightly bent at first, as a negative reading on one of the micrometers showed, and if the strain between 3 000 and 15 000 pounds be used, $E = 30\,300\,000$. In the Bessemer steel they are larger in fifteen cases out of the fifty-one, when 15 000 pounds is the limit. By taking different limits this number is reduced to eleven, as shown below—although it might be possible, on the contrary, by changing the limits in some of the other bars, to make the coefficients in compression now less than those in tension greater than them. However that may be, the conclusion to be drawn is evidently the same as in the case of the open-hearth steel.

In Table No. 5, attention is called to the following bars: Nos. 62*b* and 67*a*, in which, for the limits 1 000 and 17 000 pounds, E becomes respectively 29 739 000 and 29 535 000 greater than the corresponding values in compression. In No. 64*c* there was one abnormal strain of 0.000250 inch between 7 000 and 9 000 pounds; in No. 67*b* between 1 000 and 17 000 pounds, $E = 28\,842\,000$, still smaller than the result given; and in No. 71*b* the readings are large between 7 000 and 15 000 pounds. Between 1 000 and 17 000 pounds for this bar $E = 27\,757\,000$.

In Table No. 7, for No. 71*a*, $E = 29\,525\,000$ between 1 000 and 19 000 pounds, and for No. 72*c*, $E = 28\,959\,000$ between 1 000 and 17 000 pounds, both of which values are less than the corresponding ones in Table No. 5. In No. 74*c* the first two readings were small, and there was a negative reading on one of the micrometers. Between 1 000 and 19 000 pounds, $E = 31\,908\,000$ for this piece.

The columns, 2 inches long, used to determine the elastic limits in compression, which have already been given, were further compressed, and the stress which would produce a reduction in length of 5 and 10 per cent. was found and recorded in Tables Nos. 9 and 10. At about the last point they began to bend slightly, and no more stress was applied. No. 76 was reduced 8 per cent. in length by 50 000 pounds, the limit of the machine. This corresponds to 111 000 pounds per square inch.

In order to find the shearing resistance of this metal, the instrument shown in Plate XVI was used both for single and double shear. The pieces *A*, made of hardened tool steel, are pressed together by bringing the cover *T* upon the top one by means of the cap screws *C*, and the piece to be sheared when inserted in the orifice *H*, which was made three-quarters of an inch full in diameter, is thus held all around its exterior surface. When the instrument is placed on the platform of the machine and the cross-head is brought down on the upper surface of the block *B*, the shearing is done by the edges of the semicircular groove at the other end of this block, into which the bar fits, and which being also three-quarters of an inch full in diameter half encircles it. The width of this block, which gives the span in double shear, is two inches, and its sides just clear the vertical faces of the pairs of pieces *A*.

When a single surface is to be sheared, the bar is supported on one side only and about one and three-quarters inches projects, although experiments showed that it made no difference whether the projecting distance was more or less than this. For double shear it is pushed into the orifice in the pieces on the other side and hence is supported at each end. By this arrangement the double shear is nearly pure and the single not quite so nearly, as in this case the bar bends a little and its free end slightly leaves the shearing block.

The sheared surface was not quite elliptical in section, but was somewhat pointed at the ends of the horizontal diameter, which remained almost unchanged in length, whilst the vertical was reduced on an av-

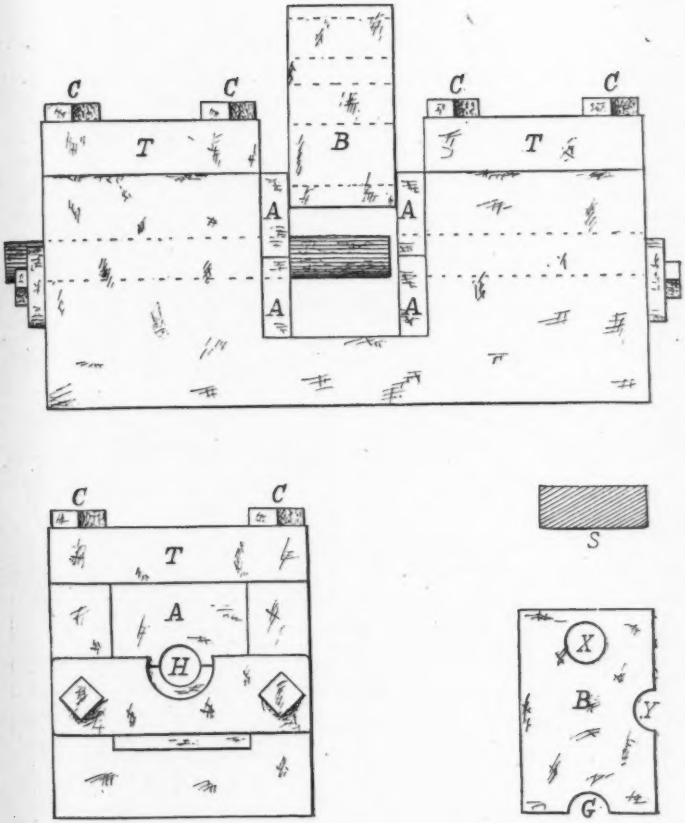

PLATE XVI.

erage to about 0.67 inch in single and 0.69 inch in double shear, giving a reduction of area of about ten per cent. in the first case and of about eight per cent. in the second.

The results of the shearing tests are found in Tables Nos. 11, 12 and 13. One piece from each of the 15-feet long rods, both of open-hearth and Bessemer steel, was tested, three times in single and the same number of times in double shear. For bars numbered 1 to 50, on account of want of material, two single and two double shears only were taken. The quantities in the columns headed "Elastic Limit" give the amount of applied stress when the metal was no longer able to hold up the scale beam. This so-called "elastic limit" is not as determinate a point as the elastic limit, found by the scale beam, of a piece in tension. The capacity of the machine was not great enough to give the double shearing resistance of all the metal tested. For some of the pieces the poise was placed beyond the 50 000-pound limit and the excess estimated. For most of these, and some of the others, it was necessary to allow the stress to remain on the specimen for times varying from ten seconds to three minutes, but all pieces for which the ratio between double and single shear is given were broken, in both, below or at the limit of the machine and without allowing the greatest stress to remain on the bar for any length of time. This ratio is seen to be greater than unity. There is given also the ratio of the ultimate resistance per square inch in double shear to that in tension. This is, of course, found to be about 75 per cent. for the rivet steel, and it is also seen to decrease both in open-hearth and Bessemer metal as the amount of carbon increases.

The shearing resistances given in Tables Nos. 11, 12 and 13 were obtained by using blocks with sharp edges. The impossibility of getting a really pure shear is known. It was the intention, however, to approach this result by means of the apparatus used. In order to reduce the bending to a minimum, the shearing block, at the risk of obtaining somewhat higher results on account of friction, was confined with but small clearance between the pieces holding the rod. In consequence of a suggestion made during the discussion of this paper, some experiments, embodied in Table No. 14, were made to find the ratio of the resistance of the metal when the shearing edges were dull to that when the edges were sharp. This ratio is given in the table, and is found to vary for the steel from 1.153 to 1.236 in single and from 1.109 to 1.141 in double shear, and for the iron to be 1.142 in single and 1.101 in double shear.

As was to be expected, it is considerably greater than unity, and this fact emphasizes the importance of rounding the edges of rivet holes in steel plates after reaming. It is doubtful, however, if these results with round edges should be taken to represent the shearing resistance of rivets in built pieces, even supposing such a mode of rupture without bending were possible, as the edges of the rivet holes would not be uniformly rounded.

The ratio between the resistance of the steel and iron when the shearing edges were sharp, is found to be about the same as when they were rounded, and it is seen generally that, whether the edges be blunt or sharp, if 7 500 pounds be allowed as the shearing resistance of iron, that of rivet steel may be taken from 15 to 20 per cent. greater, or either 8 500 or 9 000 pounds. It may be stated that these edges were blunted only slightly, the curve having a radius of from $\frac{1}{30}$ to $\frac{1}{40}$ of an inch.

For the results found in Tables Nos. 11 to 12, the groove in the shearing block was semicircular, and, as has been remarked, in single shear the rod left the block slightly. In order to find whether this reduced the resistance in single as compared with double shear, a full circular hole was made in the block, and the rod passed into it for single and through it for double shear. As the block is guided during the shear this prevented the rod from leaving the upper surface of the groove. The edges were blunt, and a comparison of the columns in Table No. 14 shows that the ratio between the resistance in single and double shear was not materially altered by confining the end of the rod.

A vertical section *s*, through the axis of the sheared piece is shown. It is seen that the rod is rounded on the lower side near the planes of shear, and this was true whether the edges were blunt or sharp, and whether the half circle or full circle of the block was used. That is, there is a certain amount of bending, and this bending would be found by any method of shearing. The effect of greater bending obtained by spacing the supporting blocks $2\frac{1}{2}$ and $2\frac{1}{4}$ inches apart, while the shearing block remains 2 inches wide, is shown by a few experiments. An examination of the ratios between the resistance per square inch in double and single shear, found in the last four tables of this paper, shows that when the shearing edges were blunt they are less than unity, and when sharp they are greater. The deviation from unity in either case is not large. The larger ratio in the last case is doubtless due to friction.

TABLE No. 1.

Strains per Inch of Length in Round Bars of Open-Hearth Steel due to 2 000 Pound Increments of Tensile Stress.

Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Mean diameter Inch.	Area square inch.	Strain in inch corresponding to the increase of the stress from							Strain on Specimen per inch of length per 1 000 pounds of stress. Inch.
						1 000 to 3 000 pounds.	3 000 to 5 000 pounds.	5 000 to 7 000 pounds.	7 000 to 9 000 pounds.	9 000 to 11 000 pounds.	11 000 to 13 000 pounds.	13 000 to 15 000 pounds.	
1	Rivet.....	0.08	0.43	0.746	0.437	0.000150	0.000152	0.000161	0.000142	0.000153	0.000145	0.000144	0.0000748
2	"	0.09	0.33	0.732	0.421	0.000159	0.000159	0.000150	0.000143	0.000156	0.000161	0.000145	0.0000745
3	"	0.09	0.35	0.747	0.438	0.000153	0.000158	0.000150	0.000158	0.000150	0.000152	0.000147	0.0000762
4	"	0.09	0.39	0.753	0.445	0.000155	0.000142	0.000147	0.000145	0.000148	0.000150	0.000128	0.0000730
5	"	0.09	.....	0.740	0.430	0.000156	0.000148	0.000169	0.000147	0.000155	0.000155	0.000158	0.0000777
6	"	0.09	.....	0.743	0.434	0.000155	0.000158	0.000147	0.000155	0.000161	0.000147	0.000139	0.0000758
7	"	0.09	.....	0.739	0.429	0.000147	0.000163	0.000153	0.000147	0.000156	0.000148	0.000147	0.0000758
8	"	0.09	.....	0.748	0.439	0.000158	0.000147	0.000147	0.000148	0.000147	0.000147	0.000145	0.0000742
9	"	0.09	.....	0.747	0.438	0.000142	0.000153	0.000148	0.000153	0.000152	0.000147	0.000144	0.0000742
10	"	0.09	.....	0.740	0.430	0.000159	0.000158	0.000147	0.000156	0.000150	0.000159	0.000152	0.0000772
11	"	0.10	.....	0.739	0.429	0.000156	0.000153	0.000159	0.000153	0.000139	0.000145	0.000141	0.0000748
12	"	0.10	.....	0.741	0.431	0.000172	0.000158	0.000156	0.000153	0.000150	0.000159	0.000142	0.0000770
13	Tension.....	0.19	0.58	0.755	0.448	0.000150	0.000142	0.000153	0.000141	0.000148	0.000153	0 000147	0.0000739
14	"	0.19	0.63	0.746	0.437	0.000164	0.000144	0.000156	0.000155	0.000152	0.000142	0.000164	0.0000769
15	"	0.20	0.57	0.739	0.429	0.000155	0.000150	0.000150	0.000158	0.000153	0.000152	0.000142	0.0000757
16	"	0.20	0.69	0.744	0.435	0.000150	0.000152	0.000152	0.000142	0.000164	0.000153	0.000148	0.0000758
17	"	0.20	0.73	0.743	0.434	0.000155	0.000148	0.000144	0.000155	0.000122	0.000183	0.000144	0.0000750
18	"	0.20	0.74	0.750	0.442	0.000161	0.000134	0.000138	0.000148	0.000148	0.000147	0.000133	0.0000721
19	"	0.20	0.76	0.757	0.450	0.000142	0.000155	0.000138	0.000144	0.000147	0.000148	0.000142	0.0000725
20	"	0.20	0.78	0.742	0.432	0.000152	0.000152	0.000155	0.000142	0.000156	0.000153	0.000152	0.0000758
21	"	0.20	0.81	0.741	0.431	0.000153	0.000148	0.000152	0.000156	0.000159	0.000145	0.000145	0.0000757
22	"	0.20	0.84	0.740	0.430	0.000148	0.000152	0.000155	0.000150	0.000153	0.000153	0.000158	0.0000763
23	"	0.20	.....	0.742	0.432	0.000155	0.000156	0.000152	0.000152	0.000155	0.000147	0.000158	0.0000767
24	"	0.21	0.63	0.750	0.442	0.000138	0.000152	0·000147	0.000147	0 000161	0.000147	0.000145	0.0000740
25	"	0·21	0.65	0.742	0.432	0.000152	0.000153	0.000158	0.000144	0.000156	0.000141	0.000150	0.0000751
26	"	0.21	0.78	0.745	0.436	0.000145	0.000152	0.000155	0.000144	0.000147	0.000155	0.000153	0.0000750
27	"	0.21	0.84	0.739	0.429	0.000150	0.000153	0.000156	0.000150	0.000152	0.000145	0.000161	0.0000762
28	"	0.21	.....	0.742	0.432	0.000155	0.000150	0.000150	0.000150	0.000150	0.000152	0.000152	0.0000756
29	"	0.22	0.58	0.744	0.435	0.000141	0.000155	0.000148	0.000163	0.000142	0.000153	0.000158	0.0000757

30	Tension.....	0.22	0.65	0.748	0.439	0.000139	0.000153	0.000148	0.000153	0.000150	0.000150	0.000139	0.0000738
31	"	0.22	0.77	0.735	0.424	0.000155	0.000150	0.000158	0.000150	0.000161	0.000153	0.000161	0.0000777
32	"	0.22	0.78	0.743	0.434	0.000150	0.000147	0.000150	0.000150	0.000155	0.000147	0.000145	0.0000746
33	"	0.24	0.82	0.741	0.431	0.000156	0.000152	0.000155	0.000155	0.000147	0.000163	0.000145	0.0000766
34	"	0.25	0.75	0.743	0.434	0.000147	0.000156	0.000152	0.000152	0.000148	0.000153	0.000144	0.0000751
35	"	0.29	0.81	0.734	0.423	0 000155	0.000153	0.000156	0.000156	0.000152	0.000163	0.000144	0.0000770
36	"	0.31	0.68	0.732	0.421	0.000153	0.000156	0.000155	0.000155	0.000159	0.000150	0.000155	0.0000773
37	Compression	0.21	1.03	0.742	0.432	0.000142	0.000150	0.000152	0.000155	0.000155	0.000148	0 000156	0.0000756
38	"	0.31	0.78	0.734	0.423	0.000147	0.000156	0.000153	0.000152	0.000155	0.000150	0.000159	0.0000766
39	"	0.31	.....	0.738	0.428	0.000156	0.000155	0.000150	0.000153	0.000147	0.000148	0.000156	0.0000761
40	"	0.32	0.79	0.740	0.430	0.000152	0.000150	0.000147	0.000161	0.000156	0.000148	0.000152	0.0000761
41	"	0.32	0.85	0.733	0.422	0.000152	0.000161	0.000159	0.000152	0.000166	0.000153	0.000152	0.0000781
42	"	0.32	.....	0.756	0.449	0.000134	0.000141	0.000145	0.000144	0.000148	0.000152	0.000145	0.0000721
43	"	0.33	0.91	0.742	0.432	0 000145	0.000152	0.000155	0.000153	0.000144	0.000155	0.000152	0.0000753
44	"	0.34	0.60	0.744	0.435	0.000150	0.000145	0.000152	0.000153	0.000150	0.000155	0.000161	0.0000761
45	"	0.36	0.89	0.736	0.425	0.000152	0.000158	0.000153	0.000152	0.000148	0.000161	0.000158	0.0000772
46	"	0.37	0.93	0.740	0.430	0.000156	0.000148	0.000156	0.000147	0.000161	0.000155	0.000145	0.0000763
47	"	0.38	0.89	0.735	0.424	0.000148	0.000152	0.000155	0.000150	0.000152	0.000163	0.000153	0.0000766
48	"	0.39	.....	0.739	0.429	0.000148	0.000150	0.000156	0.000158	0.000147	0.000159	0.000147	0.0000761
49	"	0.40	0.87	0.722	0.409	0 000175	0.000150	0.000164	0.000163	0.000158	0.000164	0.000155	0.0000806
50	"	.....	.....	0.760	0.454	0.000136	0.000147	0.000142	0.000145	0.000142	0.000134	0.000152	0.0000713
78a	"Burden's	.....	.....	0.762	0.456	0.000148	0.000144	0.000158	0.000141	0.000152	.....	.....	0.0000742
78b	Best"	.....	.....	0.761	0.455	0.000144	0.000153	0.000150	0.000145	0.000147	.....	.....	0.0000739
78c	Iron.	.....	.....	0.756	0.449	0.000148	0.000150	0.000150	0.000152	0.000153	.....	.....	0.0000753

TABLE No. 2.

STRAINS PER INCH OF LENGTH IN ROUND BARS OF OPEN-HEARTH STEEL DUE TO 2 000 POUND INCREMENTS OF COMPRESSIVE STRESS.

Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Mean diameter. Inch.	Area square. Inch.	Strain in inch corresponding to the increase of the stress from							Strain on specimen per inch of length per 1 000 pounds of stress. Inch.
						1 000 to 3 000 pounds.	3 000 to 5 000 pounds.	5 000 to 7 000 pounds.	7 000 to 9 000 pounds.	9 000 to 11 000 pounds.	11 000 to 13 000 pounds.	13 000 to 15 000 pounds.	
1	Rivet	0.08	0.43	0.746	0.437	0.000147	0.000166	0.000153	0.000150	0.000153	0.000147	0.000141	0.0000754
2	"	0.09	0.33	0.732	0.421	0.000178	0.000153	0.000172	0.000150	0.000169	0.000172	0.000153	0.0000819
3	"	0.09	0.35	0.746	0.437	0.000166	0.000156	0.000156	0.000147	0.000159	0.000156	0.000138	0.0000766
4	"	0.09	0.39	0.753	0.445	0.000153	0.000156	0.000153	0.000156	0.000150	0.000153	0.000138	0.0000757
5	"	0.09	.....	0.740	0.430	0.000172	0.000166	0.000153	0.000150	0.000160	0.000153	0.000153	0.0000795
6	"	0.09	.....	0.742	0.432	0.000169	0.000150	0.000163	0.000150	0.000156	0.000163	0.000153	0.0000788
7	"	0.09	.....	0.740	0.430	0.000159	0.000163	0.000153	0.000159	0.000156	0.000159	0.000169	0.0000799
8	"	0.09	.....	0.748	0.439	0.000163	0.000159	0.000159	0.000172	0.000156	0.000147	0.000153	0.0000775
9	"	0.09	.....	0.747	0.438	0.000166	0.000156	0.000166	0.000150	0.000163	0.000159	0.000141	0.0000786
10	"	0.09	.....	0.739	0.429	0.000169	0.000159	0.000156	0.000150	0.000156	0.000163	0.000166	0.0000799
11	"	0.10	.....	0.740	0.430	0.000153	0.000166	0.000159	0.000156	0.000153	0.000163	0.000150	0.0000786
12	"	0.10	.....	0.741	0.431	0.000156	0.000156	0.000156	0.000156	0.000153	0.000163	0.000166	0.0000772
13	Tension.....	0.19	0.58	0.757	0.450	0.000156	0.000156	0.000153	0.000153	0.000134	0.000163	0.000144	0.0000257
14	"	0.19	0.63	0.747	0.438	0.000163	0.000163	0.000159	0.000150	0.000159	0.000153	0.000147	0.0000781
15	"	0.20	0.57	0.739	0.429	0.000169	0.000159	0.000147	0.000163	0.000166	0.000153	0.000166	0.0000801
16	"	0.20	0.69	0.743	0.434	0.000159	0.000163	0.000153	0.000153	0.000166	0.000153	0.000153	0.0000786
17	"	0.20	0.73	0.744	0.435	0.000215	0.000178	0.000153	0.000156	0.000159	0.000150	0.000156	0.0000835
18	"	0.20	0.74	0.750	0.442	0.000156	0.000150	0.000159	0.000156	0.000153	0.000153	0.000156	0.0000775
19	"	0.20	0.76	0.758	0.451	0.000156	0.000156	0.000147	0.000141	0.000144	0.000159	0.000141	0.0000746
20	"	0.20	0.78	0.742	0.432	0.000150	0.000156	0.000163	0.000147	0.000156	0.000150	0.000163	0.0000775
21	"	0.20	0.81	0.742	0.432	0.000166	0.000159	0.000163	0.000156	0.000159	0.000181	0.000150	0.0000817
22	"	0.20	0.84	0.740	0.430	0.000165	0.000156	0.000156	0.000156	0.000156	0.000159	0.000153	0.0000788
23	"	0.20	.....	0.742	0.432	0.000150	0.000169	0.000156	0.000156	0.000147	0.000159	0.000159	0.0000783
24	"	0.21	0.62	0.752	0.444	0.000156	0.000163	0.000147	0.000159	0.000147	0.000156	0.000154	0.0000266
25	"	0.21	0·65	0.744	0.435	0.000172	0.000153	0.000153	0.000166	0.000147	0.000166	0.000156	0.0000795
26	"	0.21	0.78	0.745	0.436	0.000178	0.000150	0.000159	0.000150	0.000153	0.000159	0.000150	0.0000786
27	"	0.21	0.84	0.740	0.430	0.000175	0.000144	0.000166	0.000153	0.000156	0.000166	0.000150	0.0000792
28	"	0.21	.....	0.740	0.430	0.000144	0.000169	0.000163	0.000163	0.000169	0.000153	0.000163	0.0000783
29	"	0.22	0.58	0.743	0.434	0.000172	0.000156	0.000147	0.000163	0.000153	0.000153	0.000159	0.0000788

30	"	0.22	0.65	0.747	0.438	0.000172	0.000156	0.000163	0.000156	0·000156	0.000153	0.000156	0.0000795
31	"	0.22	0.77	0.736	0.425	0·000163	0.000153	0.000153	0.000159	0.000166	0.000153	0.000156	0.0000786
32	"	0.22	0.78	0.743	0.434	0.000156	0.000147	0.000156	0 000166	0 000147	0.000150	0.000141	0.0000766
33	"	0.24	0.82	0.741	0.431	0.000175	0.000150	0.000156	0.000156	0.000156	0.000159	0.000156	0.0000790
34	"	0.25	0.75	0.747	0.438	0.000150	0.000159	0.000150	0.000156	0.000153	0.000156	0.000172	0.0000772
35	"	0.29	0.81	0.735	0.424	0.000156	0.000166	0.000156	0.000156	0.000163	0.000141	0.000163	0.0000797
36	"	0.31	0.68	0.734	0.423	0.000147	0.000184	0.000163	0.000150	0.000166	0.000156	0.000144	0.0000797
37	Compression.	0.21	1.03	0.744	0.435	0.000156	0.000156	0.000166	0.000147	0.000156	0.000163	0.000156	0.0000781
38	"	0.31	0.78	0.735	0.424	0.000172	0.000163	0.000144	0.000159	0.000163	0.000156	0.000181	0.0000808
39	"	0.31	.....	0.741	0.431	0.000159	0.000156	0.000150	0.000150	0.000163	0.000150	0.000159	0.0000781
40	"	0.32	0.79	0.740	0.430	0.000159	0.000159	0.000159	0.000150	0.000159	0.000156	0.000150	0.0000790
41	"	0.32	0.85	0 733	0.422	0.000166	0.000169	0.000156	0.000169	0.000156	0.000169	0.000163	0.0000808
42	"	0.32	.....	0.757	0.450	0.000159	0.000156	0.000159	0.000131	0.000163	0.000153	0.000159	0.0000766
43	"	0.33	0.91	0.744	0.435	0.000141	0.000153	0.000159	0.000156	0.000153	0.000144	0.000147	0.0000759
44	"	0.34	0.60	0.744	0.435	0.000156	0.000156	0.000156	0.000155	0.000159	0.000153	0.000153	0.0000783
45	"	0.36	0.89	0.738	0.428	0.000159	0.000163	0.000159	0.000156	0.000156	0.000159	0.000159	0 0000795
46	"	0.37	0.93	0.740	0.430	0.000175	0.000153	0.000159	0.000147	0.000163	0.000153	0.000150	0.0000786
47	"	0.38	0.89	0.734	0.423	0.000194	0.000159	0.000156	0.000159	0·000150	0.000159	0.000150	0·0000808
48	"	0.39	.....	0.741	0.431	0.000175	0.000159	0.000166	0.000153	0.000169	0.000159	0.000156	0.0000810
49	"	0.40	0.87	0.725	0.413	0.000178	0.000166	0.000163	0.000159	0.000175	0.000150	0.000166	0.0000826
50	"	.....	.....	0.762	0.456	0.000159	0.000147	0.000150	0.000147	0.000141	0.000150	0.000156	0.0000750
78a	"Burden's	.....	.....	0.761	0.455	0.000166	0.000156	0.000159	0.000144	0.000153	0.000159	.....	0.0000778
78b	Best"	.....	.....	0.758	0.451	0.000153	0.000156	0.000138	0.000169	0.000138	0.000163	.....	0.0000747
78c	Iron.	.....	.....	0.758	0.451	0.000169	0.000156	0.000147	0.000172	0.000159	0.000153	.....	0.0000803

TABLE No. 3.

Tensile Tests of Round Bars of Open-Hearth Steel.

Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Specimen.						Per square inch.		
				Mean diameter. Inch.	Area. Square Inch.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Reduction of area. Per cent.	Elongation in 8 inches. Per cent.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Coefficient of elasticity Pounds.
1	Rivet	0.08	0.43	0.746	0.437	17 750	28 200	59.7	29.8	40 620	64 530	30 602 000
2	"	0.09	0.33	0.732	0.421	19 000	26 900	59.4	25.6	45 130	63 900	30 667 000
3	"	0.09	0.35	0.747	0.438	17 000	27 150	59.8	28.1	38 810	61 990	29 951 000
4	"	0.09	2.39	0.753	0.445	17 750	28 700	60.0	30.1	39 890	64 490	30 787 000
5	"	0.09	....	0.740	0.430	19 000	28 050	57.4	29.8	44 190	65 230	29 938 000
6	"	0.09	....	0.743	0.434	17 500	27 400	53.5	26.9	40 320	63 130	30 405 000
7	"	0.09	....	0.739	0.429	16 750	26 600	60.1	31.1	39 040	62 000	30 760 000
8	"	0.09	....	0.748	0.439	17 750	28 500	62.4	30.2	40 430	64 920	30 692 000
9	"	0.09	....	0.747	0.438	17 500	27 760	65.5	31.1	39 950	63 380	30 762 000
10	"	0.09	....	0.740	0.430	17 500	26 230	63.7	31.2	40 700	61 000	30 112 000
11	"	0.10	....	0.739	0.429	16 250	26 100	62.0	30.4	37 880	60 840	31 173 000
12	"	1.10	....	0.741	0.431	17 250	27 280	61.7	30.0	40 020	63 290	29 783 000
13	Tension.....	0.19	0.58	0.755	0.448	20 750	33 500	53.3	28.0	46 320	74 780	30 211 000
14	"	0.19	0.63	0.746	0.437	22 750	33 000	50.3	23.0	52 060	75 520	29 758 000
15	"	0.20	0.57	0.739	0.429	18 750	30 320	49.7	26.0	43 710	70 680	30 805 000
16	"	0.20	0.69	0.744	0.435	19 500	31 600	60.9	25.9	44 830	72 640	30 335 000
17	"	0.20	0.73	0.743	0.434	20 000	32 500	58.1	29.4	46 080	74 880	30 722 000
18	"	0.20	0.74	0.750	0.442	18 750	30 350	35.5	13.2	42 420	68 670	31 380 000
19	"	0.20	0.76	0.757	0.450	21 000	35 620	57.1	25.4	46 670	79 160	30 632 000
20	"	0.20	0.78	0.742	0.432	19 250	31 050	57.4	26.0	44 560	71 880	30 546 000
21	"	0.20	0.81	0.741	0.431	18 500	30 550	60.1	27.9	42 920	70 880	30 662 000
22	"	0.20	0.84	0.740	0.430	19 750	33 350	51.9	27.2	45 930	77 560	30 464 000
23	"	0.20	....	0.742	0.432	19 750	33 100	46.8	24.2	45 720	76 620	30 190 000
24	"	0.21	0.63	0.750	0.442	20 000	32 500	56.6	29.2	45 250	73 530	30 575 000
25	"	0.21	0.65	0.742	0.432	20 750	32 320	50.9	26.7	48 030	74 810	30 818 000
26	"	0.21	0.78	0.745	0.436	21 500	34 580	53.4	26.4	49 310	79 310	30 581 000
27	"	0.21	0.84	0.739	0.429	20 250	33 470	50.6	25.8	47 200	78 020	30 579 000
28	"	0.21	....	0.742	0.432	19 750	33 200	51.2	26 4	45 720	76 850	30 636 000
29	"	0.22	0.58	0.744	0.435	19 750	34 900	47.1	25.7	45 400	80 230	30 380 000

30	"	0.22	0.65	0.748	0.439	21 000	33 490	61.3	26.2	47 840	76 290	30 877 000
31	"	0.22	0.77	0.735	0.424	23 500	34 270	55.4	24.1	55 420	80 820	30 362 000
32	"	0.22	0.78	0.743	0.434	19 250	32 700	52.1	26.6	44 360	75 350	30 106 000
33	"	0.24	0.82	0.741	0.431	20 750	35 280	54.8	23.4	48 140	81 860	30 304 000
34	"	0.25	0.75	0.743	0.434	20 900	35 500	51.1	24.2	48 160	81 800	30 676 000
35	"	0.29	0.81	0.734	0.423	21 500	36 420	49.9	25.5	50 830	86 100	30 699 000
36	"	0.31	0.68	0.732	0.421	18 000	33 020	53.4	24.4	42 760	78 430	30 711 000
37	Compression.	0.21	1.03	0.742	0.432	21 000	35 240	59.0	25.6	48 610	81 580	30 636 000
38	"	0.31	0.78	0.734	0.423	20 500	34 050	53.7	24.4	48 460	80 500	30 878 000
39	"	0.31	....	0.738	0.428	21 750	35 690	49.5	24.2	50 820	83 390	30 696 000
40	"	0.32	0.79	0.740	0.430	19 500	33 100	56.7	26.8	45 350	76 980	30 553 000
41	"	0.32	0.85	0.733	0.422	20 000	34 950	51.9	24.5	47 390	82 820	30 332 000
42	"	0.32	....	0.756	0.449	25 000	41 520	51.7	24.1	55 680	92 470	30 891 000
43	"	0.33	0.91	0.742	0.432	22 250	36 450	55.8	25.4	51 390	84 380	30 726 000
44	"	0.34	0.60	0.744	0.435	22 250	36 000	49.9	24.9	51 150	82 760	30 202 000
45	"	0.36	0.89	0.736	0.425	22 750	37 630	55.5	24.4	53 530	88 540	30 465 000
46	"	0.37	0.93	0.740	0.430	21 250	37 500	52.8	23.2	49 420	87 210	30 464 000
47	"	0.38	0.89	0.735	0.424	24 000	39 750	27.8	16.9	56 600	93 750	30 805 000
48	"	0.39	....	0.739	0 429	22 250	39 500	44.8	21.9	51 860	92 070	30 624 000
49	"	0.40	0.87	0.722	0.409	21 250	35 700	46.7	22.4	51 960	87 290	30 342 000
50	"	....	....	0.760	0.454	25 250	38 900	55.9	26.9	55 620	85 680	30 885 000

TABLE No. 4.

TENSILE TESTS OF SPECIMENS FROM THE CENTER AND ENDS OF ROUND BARS OF OPEN-HEARTH STEEL.

Number.	Kind.	Per cent. of carbon.	Specimen.						Per square inch.				Comparison of ultimate resistances in the same bar.		
			Mean diameter. Inch.	Area. Square inch.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Reduction of area. Per cent.	Elongation in eight inches. Per cent.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Coefficient of elasticity. Pounds.	Mean of the coefficients of elasticity in the same bar.	Mean of the ultimate resistances per square inch.	Ratio of the mean ultimate resistance to the greatest deviation from the mean.	Ratio of the largest ultimate resistance to the smallest.
51a	Rivet.....	About 0.09	0.756	0.449	17 800	28 550	61.7	30.5	39 605	63 600	30 939 000				
51b	"	"	0.758	0.451	17 500	28 550	61.7	30.5	38 800	63 300	30 010 000	30 703 000	63 230	0.994	1.010
51c	"	"	0.757	0.450	17 000	28 350	60.8	28.9	37 800	63 000	31 160 000				
52a	"	"	0.757	0.450	17 000	27 900	65.3	29.6	37 800	62 000	31 063 000				
52b	"	"	0.758	0.451	17 400	28 500	65.1	29.4	38 600	63 200	30 471 000	30 499 000	62 670	1.011	1.019
52c	"	"	0.758	0.451	17 750	28 250	62.3	29.9	39 400	62 800	29 965 000				
53a	"	"	0.760	0.454	16 000	27 500	61.6	30.1	37 400	60 600	30 456 000				
53b	"	"	0.760	0.454	16 750	27 850	60.6	29.6	36 900	61 300	30 885 000	29 559 000	61 270	1.011	1.021
53c	"	"	0.760	0.454	17 750	28 100	61.8	32.2	39 100	61 900	27 335 000				
54a	"	"	0.760	0.454	17 250	28 300	57.9	29.2	38 160	62 500	30 618 000				
54b	"	"	0.759	0.452	16 750	28 150	62.4	28.4	37 100	62 300	30 172 000	30 405 000	62 050	1.011	1.018
54c	"	"	0.758	0.451	16 500	27 700	61.0	28.2	36 600	61 400	30 424 000				
55a	"	"	0.756	0.449	16 000	27 700	65.7	28.6	35 600	61 700	29 696 000				
55b	"	"	0.755	0.448	16 500	27 600	64.7	29.0	36 800	61 600	30 075 000	30 047 000	61 800	0.995	1.008
55c	"	"	0.754	0.447	16 500	27 750	64.3	29.1	36 900	62 100	30 371 000				
56a	"	"	0.757	0.450	16 500	27 550	63.4	27.9	36 700	61 200	30 918 000				
56b	"	"	0.758	0.451	17 000	27 900	60.4	30.4	37 700	61 900	30 801 000	30 937 000	61 630	1.007	1.011
56c	"	"	0.758	0.451	16 750	27 850	64.3	29.2	37 100	61 800	31 091 000				
57a	"	"	0.757	0.450	17 000	28 300	51.7	30.1	37 800	62 900	30 032 000				
57b	"	"	0.756	0.448	17 250	28 500	49.4	29.2	38 500	63 600	31 646 000	30 570 000	62 600	1.021	1.038
57c	"	"	0.757	0.450	17 000	27 600	51.2	28.1	37 800	61 300	30 032 000				

58a	"	"	0.750	0.442	16 000	27 150	62.1	30.9	36 200	61 200	30 166 000				
58b	"	"	0.749	0.441	16 250	27 500	60.5	29.6	36 800	62 400	30 415 000	30 272 000	61 870	1.011	1.020
58c	"	"	0.751	0.443	16 750	27 450	61.3	31.7	37 800	62 000	30 233 000				
59a	"	"	0.752	0.444	16 150	27 700	64.3	29.4	36 400	62 400	30 030 000				
59b	"	"	0.754	0.447	16 250	27 600	63.0	29.4	36 400	61 740	30 556 000	30 199 000	62 130	1.006	1.011
59c	"	"	0.749	0.441	16 200	27 450	62.3	29.2	36 700	62 240	30 011 000				
60a	"	"	0.752	0.444	16 500	27 350	55.1	29.9	37 200	61 600	30 210 000				
60b	"	"	0.757	0.450	16 500	27 050	53.7	31.0	36 700	60 100	32 965 000	31 091 000	60 900	1.013	1.025
60c	"	"	0.753	0.445	17 500	27 150	53.2	32.0	39 300	61 000	30 097 000				
78a	"Burden's	.....	0.762	0.456	12 750	23 500	50.9	29.4	27 960	51 540	29 647 000				
78b	Best"	.....	0.761	0.455	12 500	23 700	53.6	33.5	27 470	52 090	29 738 000	29 652 000	51 400	1.016	1.030
78c	Iron.	.....	0.756	0.449	12 750	22 700	52.6	28.9	28 400	50 560	29 572 000				

TABLE No. 5.

Tensile Tests of Specimens from the Center and Ends of Round Bars of Bessemer Steel.

Number.	Per cent. of carbon.	Specimen.						Per square inch.				Comparison of ultimate resistances in the same bar.		
		Mean diameter. Inch.	Area. Square inch.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Reduction of area. Per cent.	Elongation in 8 inches. Per cent.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Coefficient of elasticity. Pounds.	Mean of the coefficients of elasticity in the same bar.	Mean of the ultimate resistances per square inch.	Ratio of the mean ultimate resistance to the greatest deviation from the mean.	Ratio of the largest ultimate resistance to the smallest.
61*a*	0.11	0.748	0.439	18 200	29 250	60.3	28.4	41 460	66 630	28 950 000	.....	.....	.....	.....
61*b*	0.11	0.754	0.447	18 500	29 150	58.3	28.2	41 390	65 210	29 391 000	29 413 000	66 270	1.016	1.027
61*c*	0.11	0.750	0.442	19 200	29 600	57.0	28.2	43 440	66 970	29 899 000	.....	.....	.....	.....
62*a*	0.12	0.751	0.443	18 400	28 950	59.7	27.4	41 540	65 350	29 186 000	.....	.....	.....	.....
62*b*	0.12	0.750	0.442	18 150	28 800	59.2	28.5	41 060	65 160	29 252 000	29 225 000	65 410	0.995	1.009
62*c*	0.12	0.750	0.442	18 300	29 050	57.4	27.0	41 400	65 720	29 464 000	.....	.....	.....	.....
63*a*	0.12	0.747	0.438	18 400	28 970	57.3	30.6	42 010	66 140	29 907 000	.....	.....	.....	.....
63*b*	0.12	0.750	0.442	18 800	28 890	62.4	30.1	41 860	65 360	29 899 000	29 692 000	65 620	0.992	1.012
63*c*	0.12	0.751	0.443	18 300	28 950	57.1	28.7	41 310	65 350	29 270 000	.....	.....	.....	.....
64*a*	0.12	0.754	0.447	18 500	28 650	53.9	28.1	41 200	64 200	29 477 000	.....	.....	.....	.....
64*b*	0.12	0.752	0.444	19 000	28 500	56.8	30.1	42 800	64 190	30 023 000	28 936 000	64 210	1.0003	1.0006
64*c*	0.13	0.749	0.441	19 000	28 300	56.2	27.4	43 200	64 220	27 308 000	.....	.....	.....	.....
65*a*	0.13	0.763	0.457	22 000	31 700	58.1	26.8	48 140	69 360	29 706 000	.....	.....	.....	.....
65*b*	0.13	0.760	0.454	21 500	31 480	59.5	27.0	47 360	69 340	29 500 000	29 481 000	69 620	0.992	1.011
65*c*	0.13	0.760	0.454	21 400	31 850	56.4	27.1	47 140	70 150	29 238 000	.....	.....	.....	.....
66*a*	0.13	0.763	0.457	19 300	30 350	59.1	28.2	42 230	65 320	29 439 000	.....	.....	.....	.....
66*b*	0.13	0.760	0.454	19 200	29 800	56.6	27.6	42 290	65 640	29 678 000	29 502 000	65 770	0.991	1.016
66*c*	0.13	0.756	0.449	19 000	29 790	58.3	27.0	42 310	66 350	29 389 000	.....	.....	.....	.....
67*a*	0.15	0.749	0.441	18 000	29 500	54.7	26.0	40 900	66 900	28 860 000	.....	.....	.....	.....
67*b*	0.15	0.748	0.439	19 000	29 550	56.4	26.5	43 200	67 300	29 157 000	26 730 000	66 940	0.981	1.033
67*c*	0.16	0.754	0.447	19 000	29 350	56.9	27.4	42 500	65 700	22 173 000	27 984 000	.....	.....	.....
67*d*	0.15	0.746	0.437	18 000	29 650	56.2	28.7	41 200	67 850	31 447 000	.....	.....	.....	.....
68*a*	0.15	0.753	0.445	18 500	30 650	45.7	24.6	41 500	68 880	30 324 000	.....	.....	.....	.....
68*b*	0.16	0.755	0.448	19 000	30 300	54.2	27.7	42 400	67 630	29 240 000	29 676 000	68 250	0.991	1.018
68*c*	0.16	0.760	0.442	18 500	30 200	52.0	26.2	41 900	68 230	29 464 000	.....	.....	.....	.....

69a	0.16	0.747	0.438	18 400	29 900	54.8	28.9	43 010	68 260	30 083 000	.....	.....	.....	1.005
69b	0.16	0.745	0.436	18 200	29 860	55.7	27.6	41 740	68 480	30 266 000	29 980 000	68 440	1.003	.....
69c	0.16	0.745	0.436	17 900	29 900	53.0	27.4	41 060	68 580	29 442 000	.....	.....	.....	.....
70a	0.17	0.746	0.437	18 400	30 750	56.3	27.1	42 110	70 370	29 375 000	.....	.....	.....	.....
70b	0.17	0.744	0.435	18 600	30 660	57.2	27.4	42 760	70 480	30 168 000	30 103 000	70 140	1.008	1.013
70c	0.17	0.749	0.441	18 300	30 680	55.8	27.1	41 500	69 670	30 784 000	.....	.....	.....	.....
71a	0.17	0.748	0.439	19 500	31 450	51.9	25.5	44 400	71 670	30 372 000	.....	.....	.....	.....
71b	0.17	0.746	0.437	19 600	31 450	46.9	23.6	44 600	71 970	26 978 000	28 694 000	71 880	0.996	1.008
71c	0.18	0.747	0.438	19 500	31 600	46.8	23.9	44 500	72 110	28 731 000	.....	.....	.....	.....
72a	0.20	0.759	0.453	20 000	31 800	47.3	25.9	44 200	70 280	30 151 000	.....	.....	.....	.....
72b	0.18	0.756	0.449	20 000	31 850	52.0	27.5	44 500	70 960	30 987 000	30 161 000	70 510	1.006	1.010
72c	0.20	0.756	0.449	20 000	31 550	53.8	26.4	44 500	70 290	29 946 000	.....	.....	.....	.....
73a	0.22	0.758	0.451	22 000	34 600	49.6	25.0	48 800	76 670	29 741 000	.....	.....	.....	.....
73b	0.22	0.757	0.450	22 000	34 650	51.9	25.2	48 900	76 980	29 807 000	29 711 000	76 760	1.003	1.005
73c	0.23	0.755	0.448	22 000	34 300	51.5	25.2	49 000	76 610	29 586 000	.....	.....	.....	.....
74a	0.23	0.756	0.449	21 000	32 700	45.1	25.0	46 800	72 850	30 054 000	.....	.....	.....	.....
74b	0.24	0.757	0.450	22 000	32 850	45.3	24.4	48 900	72 980	31 307 000	31 273 000	72 740	0.995	1.008
74c	0.23	0.763	0.457	22 000	33 100	48.6	24.7	48 140	72 400	32 460 000	.....	.....	.....	.....
75a	0.24	0.754	0.447	21 000	34 100	51.9	25.1	47 090	76 370	30 938 000	.....	.....	.....	.....
75b	0.23	0.756	0.449	20 500	34 150	50.1	24.6	45 710	76 980	30 987 000	30 878 000	76 110	1.003	1.006
75c	0.24	0.759	0.453	21 000	34 350	48.5	25.2	46 400	75 890	30 713 000	.....	.....	.....	.....
76a	0.36	0.755	0.448	27 750	44 350	40.7	20.5	60 990	97 470	29 945 000	.....	.....	.....	.....
76b	0.36	0.756	0.449	27 100	44 700	38.5	19.1	60 360	99 550	30 236 000	29 787 000	98 710	1.013	1.021
76c	0.36	0.759	0.452	27 000	44 800	39.5	19.4	59 730	99 120	29 989 000	.....	.....	.....	.....
77a	0.39	0.763	0.457	27 200	43 770	39.0	20.0	59 520	95 780	30 025 000	.....	.....	.....	.....
77b	0.39	0.762	0.456	27 200	43 860	36.8	19.2	59 650	96 180	30 944 000	30 086 000	95 720	1.005	1.010
77c	0.39	0.765	0.460	27 200	43 790	36.7	19.0	59 130	95 200	29 291 000	.....	.....	.....	.....

TABLE No. 6.

Compression Tests of Columns of Open-Hearth Steel Six Inches Long.

Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Mean diameter. Inch.	Area. Square inch.	Elastic limit. Pounds.		Ultimate resistance. Pounds.	Length after test. Inches.	Co-efficient of elasticity. Pounds.
						Actual.	Per square inch.			
1	Rivet	0.08	0.43	0.746	0.437	17 000	38 720	20 300	5.68	30 330 000
2	"	0.09	0.33	0.732	0.421	20 250	47 870	23 500	5.72	28 995 000
3	"	0.09	0.35	0.746	0.437	17 250	39 380	19 800	5.66	29 888 000
4	"	0.09	0.39	0.753	0.445	18 750	41 950	21 480	5.66	29 697 000
5	"	0.09	....	0.740	0.430	20 500	47 670	21 300	5.71	29 266 000
6	"	0.09	....	0.742	0.432	18 000	41 470	19 740	5.69	29 378 000
7	"	0.09	....	0.740	0.430	17 750	41 370	19 500	5.64	29 102 000
8	"	0.09	....	0.748	0.439	19 500	44 420	21 000	5.65	29 409 000
9	"	0.09	....	0.747	0.438	19 000	43 380	20 000	5.67	29 058 000
10	"	0.09	....	0.739	0.429	17 750	41 180	19 300	5.70	29 170 000
11	"	0.10	....	0.740	0.430	17 250	40 120	19 900	5.54	29 598 000
12	"	0.10	....	0.741	0.431	17 750	41 180	20 400	5.67	30 042 000
13	Tension	0.19	0.58	0.757	0.450	21 750	48 230	24 700	5.66	29 367 000
14	"	0.19	0.63	0.747	0.438	25 000	57 080	24 950	5.80	29 224 000
15	"	0.20	0.57	0.739	0.429	19 500	45 240	23 500	5.69	29 089 000
16	"	0.20	0.69	0.743	0.434	22 000	50 570	22 900	5.72	29 325 000
17	"	0.20	0.73	0.744	0.435	21 500	49 540	23 400	5.71	27 537 000
18	"	0.20	0.74	0.750	0.442	19 500	44 020	24 150	5.71	29 210 000
19	"	0.20	0.76	0.758	0.451	22 500	50 000	27 500	5.71	29 741 000
20	"	0.20	0.78	0.742	0.432	21 000	48 280	21 120	5.67	29 888 000
21	"	0.20	0.81	0.742	0.432	20 200	46 870	23 700	5.67	28 334 000
22	"	0.20	0.84	0.740	0.430	20 500	47 560	25 [illegible]80	5.72	29 514 000
23	"	0.20	....	0.742	0.432	21 000	48 390	23 7[illegible]9	5.75	29 545 000
24	"	0.21	0.63	0·752	0.444	21 250	47 860	24 100	5.70	29 417 000
25	"	0.21	0.65	0.744	0.435	22 250	51 150	23 080	5.66	28 928 000
26	"	0.21	0.78	0.745	0.436	22 750	52 180	25 600	5.71	29 191 000
27	"	0.21	0.84	0.740	0.430	21 250	49 300	23 800	5.69	29 348 000
28	"	0.21	....	0.740	0.430	21 500	49 090	24 650	5.66	29 683 000
29	"	0.22	0.58	0.643	0.434	21 000	48 280	26 840	5.76	29 242 000
30	"	0.22	0.65	0.747	0.438	21 700	49 540	24 600	5.71	28 731 000
31	"	0.22	0.77	0.736	0.425	24 250	57 060	24 250	5.73	29 946 000

32	Tension.....	0.22	0.78	0.743	0.434	20 000	46 080	25 000	5.68	30 095 000
33	"	0.24	0.82	0.741	0 431	22 000	50 930	25 700	5.72	29 356 000
34	"	0.25	0.75	0.747	0·438	22 250	51 030	26 850	5.75	29 562 000
35	"	0.29	0.81	0.735	0.424	22 750	53 150	27 000	5.72	29 597 000
36	"	0.31	0.68	0.734	0.423	19 800	46 810	25 050	5.72	29 667 000
37	Compression	0.21	1.03	0.744	0.435	23 000	52 870	25 250	5.72	29 425 000
38	"	0.31	0.78	0.735	0.424	21 500	50 590	25 100	5.67	29 188 000
39	"	0.31	....	0.741	0.431	23 250	54 070	27 350	5.71	29 698 000
40	"	0.32	0.79	0.740	0.430	20 500	47 560	25 350	5.71	29 431 000
41	"	0.32	0.85	0.733	0.422	20 750	49 050	26 200	5.74	29 326 000
42	"	0.32	....	0.757	0.450	27 000	59 730	30 870	5.71	29 025 000
43	"	0.33	0.91	0.744	0.435	24 250	55 750	26 550	5.72	30 291 000
44	"	0.34	0.60	0.744	0.433	23 800	54 590	26 450	5.72	29 341 000
45	"	0.36	0.89	0.738	0.428	23 500	55 040	28 100	5.75	29 402 000
46	"	0.37	0.93	0.740	0.430	22 000	51 160	27 500	5.72	29 598 000
47	"	0.38	0.89	0.734	0.423	25 250	59 410	30 400	5.79	29 257 000
48	"	0.39	....	0.741	0.431	23 800	55 220	27 500	5.77	28 635 000
49	"	0.40	0.87	0.725	0.413	22 000	53 400	27 100	5.73	29 317 000
50	"	....	....	0.762	0.456	25 500	55 920	28 300	5.68	29 240 000
			From							
51*a*	Rivet	About 0.09	0.30 to 0.50	0.757	0.450	17 750	39 400	21 040	5.56	29 896 000
51*b*	"	"	"	0.756	0.449	.....	.....	20 710	5.70	27 113 000
51*c*	"	"	"	0.757	0.450	.....	.....	20 530	5.64	28 444 000
52*a*	"	"	"	0.757	0.450	18 500	41 100	22 350	5.64	29 110 000
52*b*	"	"	"	0.757	0.450	.....	.....	20 350	5.57	29 025 000
52*c*	"	"	"	0.758	0.451	.....	.....	20 400	5.61	29 045 000
53*a*	"	"	"	0.760	0.454	18 250	40 200	20 880	5.62	30 045 000
53*b*	"	"	"	0.760	0.454	.....	.....	21 210	5.64	28 853 000
53*c*	"	"	"	0.759	0.452	.....	.....	20 530	5.60	29 411 000
54*a*	"	"	"	0.758	0.451	18 750	41 600	20 920	5.62	30 193 000
54*b*	"	"	"	0.758	0.451	.....	.....	21 520	5.68	29 302 000
54*c*	"	"	"	0.758	0.451	.....	.....	20 950	5.62	29 216 000
55*a*	"	"	"	0.753	0.445	17 250	38 600	20 690	5.64	29 013 000
55*b*	"	"	"	0.753	0.445	.....	.....	20 000	5.64	29 963 000
55*c*	"	"	"	0.754	0.447	.....	.....	20 530	5.67	29 477 000
56*a*	"	"	"	0.756	0.449	17 250	38 300	20 100	5.60	29 090 000
56*b*	"	"	"	0.757	0.450	.....	.....	21 350	5.64	29 807 000
56*c*	"	"	"	0.758	0.451	.....	.....	21 430	5.62	28 960 000
57*a*	"	"	"	0.757	0.450	18 750	41 300	20 940	5.66	29 630 000
57*b*	"	"	"	0.757	0.450	.....	.....	21 330	5.60	28 940 000
57*c*	"	"	"	0.756	0.449	.....	.....	20 780	5.70	29 695 000
58*a*	"	"	"	0.753	0.445	17 750	39 900	21 580	5.62	29 437 000
58*b*	"	"	"	0.751	0.443	.....	.....	19 730	5.65	30 008 000
58*c*	"	"	"	0.751	0.443	.....	.....	20 300	5.65	28 730 000
59*a*	"	"	"	0.756	0.449	17 750	39 700	20 400	5.68	29 005 000

TABLE No. 6.—*Continued.*

Number.	Kind.	Per cent. of carbon,	Per cent. of manganese.	Mean diameter. Inch.	Area. Square inch.	Elastic limit, Pounds.		Ultimate resistance. Pounds.	Length after test. Inches.	Co-efficient of elasticity. Pounds.
						Actual.	Per square inch.			
59*b*	Rivet	About 0.09	From 0.30 to 0.50	0.754	0.447	.....	.....	20 700	5.64	29 740 000
59*c*	"	"	"	0.753	0.445	.....	.....	21 060	5.66	29 963 000
60*a*	"	"	"	0.752	0.444	17 750	39 700	19 320	5.56	31 433 000
60*b*	"	"	"	0.752	0.444	.....	.....	20 210	5.60	29 782 000
60*c*	"	"	"	0.754	0.447	.....	.....	19 750	5.50	29 391 000
78*a*	"Burden's	....	....	0.761	0.455	19 250	42 310	19 450	5.66	28 245 000
78*b*	Best"	....	....	0.758	0.451	20 000	44 350	18 950	5.64	29 687 000
78*c*	Iron.	....	....	0.758	0.451	19 500	43 240	19 100	5.62	27 608 000

TABLE No. 7.

Compression Tests of Columns of Bessemer Steel Six Inches Long.

Number.	Per cent. of carbon.	Mean diameter. Inch.	Area. Square inch.	Elastic limit. Pounds.		Ultimate resistance. Pounds.	Coefficient of elasticity. Pounds.
				Actual.	Per square inch.		
61*a*	0.11	0.751	0.443	18 500	42 000	22 150	28 567 000
61*b*	0.11	0.751	0.443			21 800	29 149 000
61*c*	0.11	0.752	0.444			22 390	28 747 000
62*a*	0.12	0.752	0.444	18 250	41 000	22 780	28 503 000
62*b*	0.12	0.749	0.441			23 010	29 531 000
62*c*	0.12	0.751	0.443			21 900	28 730 000
63*a*	0.12	0.752	0.444	18 750	42 000	21 800	29 162 000
63*b*	0.12	0.750	0.442			22 500	29 210 000
63*c*	0.12	0.754	0.447			21 390	28 635 000
64*a*	0.12	0.750	0.442	20 000	45 500	23 300	28 471 000
64*b*	0.12	0.753	0.445			22 500	30 324 000
64*c*	0.13	0.750	0.442			21 900	28 155 000
65*a*	0.13	0.762	0.456	20 250	44 400	25 150	28 070 000
65*b*	0.13	0.759	0.452			24 340	28 729 000
65*c*	0.13	0.757	0.450			24 240	29 025 000
66*a*	0.13	0.760	0.454	20 000	44 000	22 860	29 281 000
66*b*	0.13	0.758	0.451			23 060	29 830 000
66*c*	0.13	0.759	0.452			23 330	29 324 000
67*a*	0.15	0.749	0.441	24 500	55 600	22 700	29 531 000
67*b*	0.15	0.744	0.435			22 500	29 594 000
67*c*	0.16	0.748	0.439			21 900	29 325 000
68*a*	0.15	0.753	0.445	21 250	47 700	24 000	29 126 000
68*b*	0.16	0.749	0.441			23 800	30 234 000
68*c*	0.16	0.752	0.444			23 800	20 332 000
69*a*	0.16	0.747	0.438	18 000	41 000	21 700	29 812 000
69*b*	0.16	0.744	0.435			21 790	29 341 000
69*c*	0.16	0.748	0.439			22 850	28 666 000
70*a*	0.17	0.749	0.441	18 250	41 300	22 800	28 860 000
70*b*	0.17	0.748	0.439			22 960	29 241 000
70*c*	0.17	0.746	0.437			22 710	29 802 000
71*a*	0.17	0.748	0.439	21 250	48 800	24 400	30 738 000

TABLE No. 7.—*Continued.*

Number.	Per cent of carbon.	Mean diameter. Inch.	Area. Square inch.	Elastic limit. Pounds.		Ultimate resistance. Pounds.	Coefficient of elasticity. Pounds.
				Actual.	Per square inch.		
71*b*	0.17	0.747	0.438			24 800	30 441 000
71*c*	0.18	0.747	0.438			24 100	28 412 000
72*a*	0.20	0.755	0.448	21 000	47 200	23 500	30 488 000
72*b*	0.18	0.755	0.448			24 900	30 488 000
72*c*	0.20	0.754	0.447			24 450	29 477 000
73*a*	0.22	0.755	0.448	23 000	51 200	27 300	30 488 000
73*b*	0.22	0.754	0.447			27 100	29 477 000
73*c*	0.23	0.757	0.450			25 700	30 352 000
74*a*	0.23	0.755	0.448	22 500	50 100	25 000	31 644 000
74*b*	0.24	0.758	0.451			26 900	29 560 000
74*c*	0.23	0.758	0.451			25 100	33 112 000
75*a*	0.24	0.753	0.445	22 000	49 100	26 400	27 960 000
75*b*	0.23	0.757	0.450			24 750	28 283 000
75*c*	0.24	0.756	0.449			25 600	28 672 000
76*a*	0.36	0.752	0.444	24 500	54 300	33 040	29 162 000
76*b*	0.36	0.757	0.450			34 620	29 454 000
76*c*	0.36	0.757	0.450			33 550	29 281 000
77*a*	0.39	0.760	0.454	27 000	58 600	33 610	28 602 000
77*b*	0.39	0.762	0.456			30 730	28 981 000
77*c*	0.39	0.760	0.454			32 920	29 281 000

TABLE No. 8.

COMPARISON OF COEFFICIENTS OF ELASTICITY IN TENSION AND COMPRESSION.

	Per cent. of carbon.	Kind.	Number of tests.	Mark.	Coefficients of elasticity in pounds.						Ratio of the mean coefficient in tension to that in compression.
					In tension.			In compression.			
					Table.	Varies between.	Mean.	Table.	Varies between.	Mean.	
Open-Hearth Steel ..	About 0.09	Rivet.	12	1 to 12	3	29 780 000 and 31 170 000	30 470 000	6	29 000 000 and 30 330 000	29 490 000	1.033
" " ..	0.20 to 0.30	Tension.	24	13 to 36	3	29 760 000 " 31 380 000	30 570 000	6	27 540 000 " 30 090 000	29 310 000	1.043
" " ..	0.30 to 0.40	Compression.	14	37 to 50	3	30 200 000 " 30 890 000	30 610 000	6	28 630 000 " 30 290 000	29 330 000	1.043
" " ..	0.09 to 0.40	.....	50	1 to 50	3	29 760 000 " 31 380 000	30 550 000	6	27 540 000 " 30 330 000	29 390 000	1.040
" " ..	About 0.09	Rivet.	30	51*a* to 60*c*	4	27 330 000 " 31 650 000	39 430 000	6	27 110 000 " 30 430 000	29 390 000	1.035
Bessemer Steel	0.11 to 0.13	.....	18	61*a* to 66*c*	5	27 310 000 " 30 020 000	29 390 000	7	28 070 000 " 30 320 000	28 970 000	1.014
" "	0.20 to 0.24	.....	10	72*c* to 75*c*	5	29 350 000 " 32 460 000	30 490 000	7	27 960 000 " 33 110 000	29 900 000	1.020
" "	0.36 to 0.39	.....	6	76*a* to 77*c*	5	20 040 000 " 30 490 000	29 920 000	7	28 600 000 " 29 450 000	29 130 000	1.027
" "	0.11 to 0.39	.....	51	61*a* to 77*c*	5	22 170 000 " 32 460 000	29 640 000	7	27 960 000 " 33 110 000	29 370 000	1.009
"Burden's Best" Iron			3	78*a* to 78*c*	4	29 570 000 " 29 740 000	29 650 000	6	27 610 000 " 29 690 000	28 510 000	1.040

TABLE No. 9.

Compression Tests of Columns of Open-hearth Steel Two Inches Long.

Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Mean diameter. Inches.	Area. Square inch.	Stress in pounds on specimen at			Stress in pounds per square inch at		
						Elastic limit.	5 per cent. reduction of length.	10 per cent. reduction of length.	Elastic limit.	5 per cent. reduction of length.	10 per cent. reduction of length.
1	Rivet	0.08	0.43	0.748	0.439	17 000	26 540	34 600	38 720	60 450	78 820
2	"	0.09	0.33	0.724	0.423	20 250	25 150	31 800	47 870	59 460	75 180
3	"	0.09	0.35	0.747	0.438	17 250	25 000	33 100	39 380	57 080	75 570
4	"	0.09	0.39	0.754	0.447	18 750	26 000	34 650	41 950	58 160	77 520
5	"	0.09	....	0.740	0.430	20 500	26 000	33 950	47 670	60 460	78 950
6	"	0.09	....	0.743	0.434	18 000	25 550	33 400	41 470	58 870	76 960
7	"	0.09	....	0.739	0.429	17 750	25 250	32 200	41 380	58 860	75 060
8	"	0.09	....	0.748	0.439	19 500	26 000	33 800	44 420	59 230	76 990
9	"	0.09	....	0.747	0.438	19 000	26 000	33 930	43 380	59 360	77 470
10	"	0.09	....	0.741	0.431	17 750	24 890	31 540	41 180	57 750	73 180
11	"	0.10	....	0.740	0.430	17 250	24 000	31 730	40 120	56 810	73 790
12	"	0.10	....	0.741	0.431	17 750	24 980	32 700	41 180	57 960	75 870
13	Tension	0.19	0.58	0.758	0.451	21 750	30 500	41 000	48 230	67 630	90 910
14	"	0.19	0.63	0.747	0.438	25 000	32 700	38 700	57 080	74 660	88 360
15	"	0.20	0.57	0.741	0.431	19 500	27 300	36 700	49 400	63 340	85 150
16	"	0.20	0.69	0.744	0.435	22 000	29 880	37 500	50 570	68 690	86 210
17	"	0.20	0.73	0.743	0.434	21 500	30 000	38 600	49 540	69 120	88 940
18	"	0.20	0.74	0.751	0.443	19 500	28 000	37 900	44 020	63 210	93 220
19	"	0.20	0.76	0.757	0.450	22 500	29 800	42 600	50 000	66 220	94 670
20	"	0.20	0.78	0.744	0.435	21 000	30 750	36 770	48 280	70 690	84 530
21	"	0.20	0.81	0.742	0.432	20 250	28 650	37 750	46 870	66 320	87 390
22	"	0.20	0.84	0.741	0.431	20 500	30 590	39 350	47 560	70 970	91 300
23	"	0.20	....	0.743	0.434	21 000	29 900	39 600	48 390	68 890	91 240
24	"	0.21	0.63	0.752	0.444	21 250	30 790	39 100	47 860	69 350	88 060
25	"	0.21	0.65	0.744	0.435	32 250	29 700	38 750	51 150	68 280	89 080
26	"	0.21	0.78	0.745	0.436	22 750	32 540	42 550	52 180	74 630	97 500
27	"	0.21	0.84	0.741	0.431	21 250	30 500	39 500	49 300	70 760	91 650
28	"	0.21	....	0.744	0.435	21 500	31 400	40 800	49 430	72 180	93 790
29	"	0.21	0.58	0.744	0.435	21 000	32 850	42 520	48 280	75 520	97 750
30	"	0.22	0.65	0.748	0.439	21 750	30 950	39 750	49 540	70 500	90 550
31	"	0.22	0.77	0.736	0.425	24 250	32 500	40 500	57 060	76 470	95 300

31	"	0.22	0.77	0.736	0.425	24 250	32 500	40 500	57 060	76 470	95 300
32	"	0.22	0.78	0.743	0.434	20 000	29 200	37 750	46 080	67 280	86 980
33	"	0.24	0.82	0.742	0.432	22 000	33 100	41 900	50 939	76 620	96 990
34	"	0.25	0.75	0.745	0.436	22 250	33 850	42 000	51 030	77 640	96 330
35	"	0.29	0.81	0.738	0.428	22 750	33 700	43 300	53 160	78 740	101 170
36	"	0.31	0.68	0.734	0.423	19 180	29 670	38 830	46 810	70 140	91 800
37	Compression	0.21	1.03	0.744	0.435	23 000	31 800	40 900	52 870	73 100	94 020
38	"	0.31	0.78	0.736	0.425	21 500	31 700	42 600	50 590	74 590	100 270
39	"	0.31	....	0.740	0.430	30 250	33 200	42 860	54 070	77 210	99 670
40	"	0.32	0.79	0.741	0.431	20 500	30 800	39 900	47 560	71 460	92 570
41	"	0 32	0.85	0.734	0.423	20 750	31 800	41 300	49 050	75 180	97 640
42	"	0.32	....	0.759	0.452	27 090	41 000	48 800	59 730	90 710	107 970
43	"	0.33	0.91	0.744	0.435	24 250	35 600	43 800	55 750	81 840	100 700
44	"	0.34	0.60	0.745	0.436	23 800	33 200	43 640	54 590	76 140	100 100
45	"	0.36	0.89	0.737	0.427	23 500	37 500	44 600	55 040	87 820	104 450
46	"	0.37	0.93	0.740	0.430	22 000	34 850	43 660	51 160	81 050	101 540
47	"	0.38	0.89	0.736	0.425	25 250	38 000	46 900	59 410	89 410	110 350
48	"	0.39	....	0.741	0.431	23 800	37 400	46 600	55 200	86 770	108 120
49	"	0.40	0.87	0.724	0.412	22 000	33 800	42 400	53 400	82 040	102 900
50	"	....	....	0.762	0.456	25 000	36 800	47 000	55 920	80 700	103 070
51	Rivet	About 0.09	From 0.30 to 0.50	0.757	0.450	17 750	26 750	33 830	39 440	59 440	75 180
52	"	"	"	0.757	0.450	18 500	27 320	35 550	41 110	60 710	79 000
53	"	"	"	0.760	0.454	18 250	28 000	35 700	40 200	61 670	78 630
54	"	"	"	0.758	0.451	18 750	27 070	35 100	41 570	60 020	77 830
55	"	"	"	0.754	0.447	17 250	27 370	35 490	38 590	61 230	79 400
56	"	"	"	0.757	0.450	17 250	26 760	43 930	38 330	59 470	75 400
57	"	"	"	0.756	0.449	18 750	26 300	35 540	41 760	58 570	70 150
58	"	"	"	0.753	0.445	17 750	26 150	36 170	39 890	58 760	81 280
59	"	"	"	0.754	0.447	17 750	25 830	35 110	39 710	57 780	78 540
60	"	"	"	0.754	0.447	17 750	26 550	32 700	39 710	59 400	73 160
78a	"Burden's Best" iron	.....	.....	0.760	0.454	19 250	22 500	30 500	42 400	49 560	67 180
78b	"	.....	.....	0.756	0.449	20 000	23 000	29 750	44 540	51 220	66 260
78c	"	.....	.....	0.758	0.451	19 500	23 000	30 000	43 240	51 000	66 520

TABLE No. 10.

Compression Tests of Columns of Bessemer Steel Two Inches Long.

Number.	Per cent. of carbon.	Mean diameter. Inch.	Area. Square inch.	Stress in pounds on specimen at			Stress in pounds per square inch at		
				Elastic limit.	5 per cent. reduction of length.	10 per cent. reduction of length.	Elastic limit.	5 per cent. reduction of length.	10 per cent. reduction of length.
61	0.11	0.747	0.450	18 500	27 470	35 930	42 200	62 800	82 000
62	0.12	0.750	0.442	18 250	27 200	37 080	41 290	61 540	83 890
63	0.12	0.754	0.447	18 750	27 460	35 800	41 950	61 430	80 060
64	0.12	0.748	0.430	20 000	25 390	35 330	45 560	57 840	80 480
65	0.13	0.762	0.456	20 250	30 980	38 640	44 410	67 940	74 740
66	0.13	0.760	0.454	20 000	29 070	37 900	44 050	64 030	83 480
67	0.15	0.749	0.441	24 500	26 500	36 250	55 600	60 100	82 200
68	0.16	0.753	0.445	21 250	27 770	37 000	47 750	62 410	83 150
69	0.16	0.751	0.443	18 000	27 000	35 360	40 630	60 950	79 820
70	0.17	0.750	0.442	18 250	29 230	37 530	41 290	66 130	84 910
71	0.17	0.744	0.435	21 250	29 400	39 090	48 850	67 590	89 960
72	0.20	0.753	0.445	21 000	27 590	39 000	47 190	65 000	87 640
73	0.22	0.756	0.449	23 000	31 860	41 550	51 220	70 960	92 540
74	0.23	0.756	0.449	22 500	31 600	40 900	50 110	70 380	91 090
75	0.24	0.755	0.448	22 000	28 930	40 000	49 110	64 580	89 290
76	0.36	0.758	0.451	24 500	37 130	.....	54 320	82 330	.....
77	0.29	0.766	0.461	27 000	43 580	50 000	58 579	94 530	108 500

TABLE No. 11.

Shearing Resistance of Round Bars of Open-Hearth Steel.

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Number.	Kind.	Per cent. of carbon.	Per cent. of manganese.	Mean diameter. Inch.	Area. Square inch.	Single shear. Of the specimen. Elastic limit. Pounds.	Single shear. Of the specimen. Ultimate resistance. Pounds.	Single shear. Per square inch. Elastic limit. Pounds.	Single shear. Per square inch. Ultimate resistance. Pounds.	Single shear. Per square inch. Mean elastic limit for each bar. Pounds.	Single shear. Per square inch. Mean ultimate resistance for each bar. Pounds.	Double shear. Of the specimen. Elastic limit. Pounds.	Double shear. Of the specimen. Ultimate resistance. Pounds.	Double shear. Per square inch. Elastic limit. Pounds.	Double shear. Per square inch. Ultimate resistance. Pounds.	Double shear. Per square inch. Mean elastic limit for each bar. Pounds.	Double shear. Per square inch. Mean ultimate resistance for each bar. Pounds.	Ratio of ultimate resistance per square inch in double to that in single shear.	Ultimate tensile resistance per square inch. Pounds.	Ratio of ultimate resistance per square inch in double shear to that in tension.
1	Rivet	0.08	0.43	0.747	0.438	15 000	20 550	34 250	46 920	34 820	46 900	35 500	42 000	39 390	47 950	39 100	47 950	1.022	64 530	0.743
1	"					15 500	20 530	35 390	46 870			34 000	42 000	38 810	47 950					
2	"	0.09	0.33	0.732	0.421	12 500	19 800	29 690	47 030	30 280	47 060	21 500	40 000	25 530	47 510	25 530	47 750	1.015	63 900	0.747
2	"					13 000	19 820	30 880	47 080			21 500	40 400	25 530	47 980					
3	"	0.09	0.35	0.746	0.437	15 500	20 100	35 470	46 000	36 330	46 230	33 000	40 970	37 760	46 880	38 050	47 070	1.018	61 990	0.759
3	"					16 250	20 300	37 190	46 450			33 500	41 300	38 330	47 250					
4	"	0.09	0.39	0.753	0.445	16 250	20 980	36 520	47 150	35 670	47 000	29 500	42 920	33 150	48 220	33 990	48 240	1.026	64 490	0.748
4	"					15 500	20 850	34 830	46 850			31 000	42 950	34 830	48 260					
5	"	0.09	....	0.740	0.430	14 250	20 430	33 140	47 510	33 720	47 770	35 000	42 350	40 700	49 240	41 570	49 300	1.032	65 230	0.756
5	"					14 750	20 650	34 300	48 020			36 500	42 450	42 440	49 360					
6	"	0.09	....	0.743	0.434	15 000	20 400	34 560	47 000	34 560	47 170	2[illegible] 000	42 250	29 950	48 680	30 820	48 290	1.024	63 130	0.765
6	"					15 000	20 550	34 560	47 350			27 500	41 580	31 680	47 900					
7	"	0.09	....	0.739	0.429	15 250	19 550	35 550	45 570	37 000	45 540	27 000	40 300	31 470	46 970	32 350	46 890	1.030	62 000	0.756
7	"					16 500	19 520	38 460	45 500			28 500	40 150	33 220	46 800					
8	"	0.09	....	0.748	0.439	12 750	21 000	29 040	47 840	29 320	47 670	27 000	42 980	30 750	48 950	30 750	48 650	1.021	64 920	0.749
8	"					13 000	20 850	29 610	47 490			27 000	42 450	30 750	48 350					
9	"	0.09	....	0.747	0.438	12 000	20 690	27 400	47 200	27 970	47 460	24 500	42 300	27 970	48 290	25 970	48 290	1.017	63 380	0.762
9	"					12 500	20 900	28 540	47 720			21 000	42 300	27 970	48 290					
10	"	0.09	....	0.740	0.430	10 000	19 820	23 300	46 090	21 550	45 900	19 000	41 560	22 100	48 330	21 520	47 130	1.027	61 000	0.773
10	"					8 500	19 650	19 800	45 700			18 000	39 500	20 930	45 930					
11	"	0.10	....	0.737	0.427	14 000	19 350	32 790	45 320	33 370	45 380	32 000	39 300	37 470	46 020	38 060	46 020	1.014	60 840	0.756
11	"					14 500	19 400	33 960	45 430			33 000	39 300	38 640	46 020					
12	"	0.10	....	0.740	0.430	15 000	19 650	34 880	45 690	34 880	45 990	27 000	41 170	31 400	47 870	31 690	47 650	1.036	63 290	0.753
12	"					15 000	19 900	34 880	46 280			27 500	40 780	31 980	47 420					
13	Tension	0.19	0.58	0.754	0.447	22 500	24 000	50 340	53 690	50 890	54 020	45 000	48 980	50 340	54 790	50 620	54 650	1.012	74 780	0.731
13	"					23 000	24 290	51 450	54 340			45 500	48 730	50 890	54 510					
14	"	0.19	0.63	0.747	0.438	23 000	23 950	52 510	54 680	52 510	54 450	45 500	48 750	50 800	55 650	50 800	55 450	1.018	75 520	0.734
14	"					23 000	23 750	52 510	54 220			44 500	48 400	50 800	55 250					
15	"	0.20	0.57	0.740	0.430	20 500	21 090	47 670	49 050	48 300	49 300	40 500	43 600	47 090	50 700	48 260	51 100	1.036	70 680	0.723
15	"					21 000	21 310	48 840	49 560			42 500	44 350	49 420	51 500					
16	"	0.20	0.69	0.743	0.434	21 500	22 850	49 540	52 650	49 540	52 620	41 000	46 600	47 230	53 690	48 100	53 950	1.025	72 640	0.743
16	"					21 500	22 820	49 540	52 580			42 500	47 050	48 960	54 200					
17	"	0.20	0.73	0.743	0.434	22 500	23 070	51 840	53 160	51 840	53 310	46 750	47 650	53 860	54 900	53 140	55 000	1.032	74 880	0.735
17	"					25 500	23 200	51 840	53 460			45 500	47 820	52 420	55 090					
18	"	0.20	0.74	0.750	0.442	22 000	23 100	49 770	52 260	50 340	52 250	42 000	46 000	47 510	52 040	49 200	52 370	1.002	68 670	0.763
18	"					22 500	23 090	50 000	52 240			45 000	46 580	50 900	52 690					
19	"	0.20	0.76	0.757	0.450	22 500	25 650	50 000	57 000	50 000	55 170	44 500	51 000	49 450	56 670	50 280	56 670	1.027	79 160	0.716
19	"					22 500	24 000	50 500	53 330			46 000	51 000	51 110	56 670					
20	"	0.20	0.78	0.743	0.434	19 500	22 200	44 930	51 150	45 220	51 560	36 000	45 000	41 470	51 840	42 340	52 160	1.013	71 880	0.726
20	"					19 750	22 500	45 510	51 840			37 500	45 500	43 200	52 480					
21	"	0.20	0.81	0.743	0.434	21 500	21 710	49 540	50 020	49 540	50 100	43 000	44 000	49 540	50 690	49 540	51 040	1.019	70 880	0.720
21	"					19 000	21 780	49 540	50 180			43 000	44 600	49 540	51 380					
22	"	0.20	0.84	0.740	0.430	20 000	23 750	41 190	55 230	45 350	54 940	34 000	47 450	39 530	55 170	40 120	55 120	1.003	77 560	0.711
22	"					21 500	23 500	46 510	54 650			35 000	47 350	40 700	55 060					
23	"	0.20	....	0.744	0.435	21 500	23 750	49 430	54 600	50 580	54 540	42 500	47 900	48 850	55 060	49 710	55 120	1.011	76 620	0.719
23	"					22 500	23 700	51 720	54 480			44 000	48 000	50 570	55 170					
24	"	0.21	0.63	0.752	0.444	22 500	23 070	50 680	51 960	50 680	51 600	45 000	47 050	50 680	52 980	50 680	52 900	1.025	73 530	0.719
24	"					22 500	22 750	50 680	51 240			45 000	46 900	50 680	52 820					
25	"	0.21	0.65	0.743	0.434	22 000	22 800	50 690	52 540	50 120	52 300	44 000	45 680	50 690	52 630	51 560	53 130	1.016	74 810	0.710
25	"					21 500	22 600	49 540	52 070			45 000	46 550	52 420	53 630					
26	"	0.21	0.78	0.744	0.435	22 000	24 940	50 570	57 330	50 570	57 140	43 500	50 000	50 000	57 470	50 290	56 180	0.983	79 310	0.708
26	"					22 000	24 770	50 570	56 940			44 500	47 750	50 570	54 880					
27	"	0.21	0.84	0.740	0.430	21 500	22 800	50 000	53 020	50 000	53 670	44 500	48 000	51 740	55 810	51 740	56 560	1.054	78 020	0.725
27	"					21 500	23 360	50 000	54 320			44 500	49 280	51 740	57 300					
28	"	0.21	....	0.741	0.431	22 000	23 100	51 040	53 600	51 040	52 440	46 000	48 030	53 360	55 720	52 780	55 210	1.053	76 850	0.718
28	"					22 000	22 100	51 040	51 280			45 000	47 150	52 200	54 700					
29	"	0.22	0.58	0.743	0.434	22 500	24 650	51 840	56 800	52 420	56 800	45 000	50 000	51 840	54 150	53 000	55 880	.....	80 230	
29	"					23 000	24 650	53 000	56 800			47 000	50 000	54 160	57 600					
30	"	0.22	0.65	0.747	0.438	21 500	24 330	49 090	55 550	49 090	55 000	43 000	48 900	49 000	55 820	49 660	55 680	1.012	76 290	0.730
30	"					21 500	23 850	49 090	54 450			44 000	48 650	50 230	55 540					
31	"	0.22	0.77	0.736	0.425	23 000	23 740	54 120	55 860	54 120	55 810	46 500	49 380	54 710	58 090	55 000	57 900	1.037	80 820	0.716
31	"					23 000	23 700	54 120	55 760			47 000	49 050	55 290	57 710					
32	"	0.22	0.78	0.742	0.432	22 000	22 930	50 930	53 080	51 800	53 270	43 000	46 140	49 770	53 400	50 640	53 880	1.011	75 350	0.715
32	"					22 750	23 090	52 660	53 450			44 500	46 970	51 500	54 360					
33	"	0.24	0.82	0.742	0.432	20 000	24 870	46 300	57 570	46 880	57 460	38 500	50 000	44 560	57 870	47 460	57 760	.....	81 860	
33	"					20 500	24 770	47 450	57 340			43 500	49 800	50 350	57 640					
34	"	0.25	0.75	0.744	0.435	22 500	25 160	51 720	57 840	51 720	57 700	43 000	50 000	49 430	57 480	50 580	57 470	.....	81 800	
34	"					22 500	25 040	51 740	57 560			45 000	50 000	51 720	57 420					
35	"	0.29	0.81	0.736	0.425	20 000	25 370	51 760	59 690	53 820	59 690	39 000	50 000	45 880	58 720	49 410	58 820	.....	86 100	
35	"					23 750	25 370	55 880	59 690			45 000	50 000	52 940	58 820					
36	"	0.31	0.68	0.732	0.421	22 500	23 060	53 440	54 780	53 440	54 810	44 000	47 240	52 260	56 100	53 150	55 750	1.017	78 430	0.711
36	"					22 500	23 090	53 440	54 840			45 500	46 650	54 040	55 400					
37	Compression	0.21	1.03	0.741	0.431	24 000	24 500	55 680	56 840	54 520	57 080	44 500	49 890	51 620	57 880	52 200	57 730	1.011	81 580	0.708
37	"					23 000	24 500	53 360	57 310			45 500	49 630	52 780	57 580					
	"	0.31	0.78	0.733	0.422															

2	"					15 000	19 820	30 880	47 080			21 500	40 400	25 530	47 810			47 760	1.015	63 900	0.747						
3	"	0.09	0.35	0.746	0.437	15 500	20 100	35 470	46 000	36 330	46 230	33 000	40 970	37 760	46 880	38 050	47 070	1.018	61 990	0.759							
3	"					16 250	20 300	37 190	46 450			33 500	41 300	38 330	47 250												
4	"	0.09	0.39	0.753	0.445	16 250	20 980	36 520	47 150	35 670	47 000	29 500	42 920	33 150	48 220	33 990	48 240	1.026	64 490	0.748							
4	"					15 500	20 850	34 830	46 850			31 000	42 950	34 830	48 260												
5	"	0.09	....	0.740	0.430	14 250	20 430	33 140	47 510	33 720	47 770	35 000	42 350	40 700	49 240	41 570	49 300	1.032	65 230	0.756							
5	"					14 750	20 650	34 300	48 020			36 500	42 450	42 440	49 360												
6	"	0.09	....	0.743	0.434	15 000	20 400	34 560	47 000	34 560	47 170	26 000	42 250	29 950	48 680	30 820	48 290	1.024	63 130	0.765							
6	"					15 000	20 550	34 560	47 350			27 500	41 580	31 680	47 900												
7	"	0.09	....	0.739	0.429	15 250	19 550	35 550	45 570	37 000	45 540	27 000	40 300	31 470	46 970	32 350	46 890	1.030	62 000	0.756							
7	"					16 500	19 520	38 460	45 500			28 500	40 150	33 220	46 800												
8	"	0.09	....	0.748	0.439	12 750	21 000	20 040	47 840	29 320	47 670	27 000	42 980	30 750	48 950	30 750	48 650	1.021	64 920	0.749							
8	"					13 000	20 850	29 610	47 490			27 000	42 450	30 750	48 350												
9	"	0.09	....	0.747	0.438	12 000	20 690	27 400	47 200	27 970	47 460	24 500	42 300	27 970	48 290	25 970	48 290	1.017	63 380	0.762							
9	"					12 500	20 900	28 540	47 720			21 000	42 300	27 970	48 290												
10	"	0.09	....	0.740	0.430	10 000	19 820	23 300	46 090	21 550	45 900	19 000	41 560	22 100	48 330	21 520	47 130	1.027	61 000	0.773							
10	"					8 500	19 650	19 800	45 700			18 000	39 500	20 930	45 930												
11	"	0.10	....	0.737	0.427	14 000	19 350	32 790	45 320	33 370	45 380	32 000	39 300	37 470	46 020	38 060	46 020	1.014	60 840	0.756							
11	"					14 500	19 400	33 960	45 430			33 000	39 300	38 640	46 020												
12	"	0.10	....	0.740	0.430	15 000	19 650	34 880	45 690	34 880	45 990	27 000	41 170	31 400	47 870	31 690	47 650	1.036	63 290	0.753							
12	"					15 000	19 900	34 880	46 280			27 500	40 780	31 580	47 420												
13	Tension.....	0.19	0.58	0.754	0.447	22 500	24 000	50 340	53 690	50 890	54 020	45 000	48 980	50 340	54 790	50 620	54 650	1.012	74 780	0.731							
13	"					23 000	24 290	51 450	54 340			45 500	48 730	50 690	54 510												
14	"	0.19	0.63	0.747	0.438	23 000	23 950	52 510	54 680	52 510	54 450	45 500	48 750	50 800	55 650	50 800	55 450	1.018	75 520	0.734							
14	"					23 000	23 750	52 510	54 220			44 500	48 400	50 800	55 250												
15	"	0.20	0.57	0.740	0.430	20 500	21 090	47 670	49 050	48 300	49 300	40 500	43 600	47 090	50 700	48 260	51 160	1.036	70 680	0.723							
15	"					21 000	21 310	48 840	49 560			42 500	44 350	49 420	51 500												
16	"	0.20	0.69	0.743	0.434	21 500	22 850	49 540	52 650	49 540	52 620	41 000	46 600	47 230	53 690	48 100	53 950	1.025	72 640	0.743							
16	"					21 500	22 820	49 540	52 580			42 500	47 050	48 960	54 200												
17	"	0.20	0.73	0.743	0.434	22 500	23 070	51 840	53 160	51 840	53 310	46 750	47 650	53 860	54 900	53 140	55 000	1.032	74 880	0.735							
17	"					25 500	23 200	51 840	53 460			45 500	47 820	52 420	55 090												
18	"	0.20	0.74	0.750	0.442	22 000	23 100	49 770	52 260	50 340	52 250	42 000	46 000	47 510	52 040	49 200	52 370	1.002	68 670	0.763							
18	"					22 500	23 090	50 000	52 240			45 000	46 580	50 900	52 690												
19	"	0.20	0.76	0.757	0.450	22 500	25 650	50 000	57 000	50 000	55 170	44 500	51 000	49 450	56 670	50 280	56 670	1.027	79 160	0.716							
19	"					22 500	24 000	50 500	53 330			46 000	51 000	51 110	56 670												
20	"	0.20	0.78	0.743	0.434	19 500	22 200	44 930	51 150	45 220	51 500	36 000	45 000	41 470	51 840	42 340	52 160	1.013	71 880	0.726							
20	"					19 750	22 500	45 510	51 840			37 500	45 500	43 200	52 480												
21	"	0.20	0.81	0.743	0.434	21 500	21 710	49 540	50 020	49 540	50 100	43 000	44 000	49 540	50 690	49 540	51 040	1.019	70 880	0.720							
21	"					19 000	21 780	49 540	50 180			43 000	44 600	49 540	51 380												
22	"	0.20	0.84	0.740	0.430	20 000	23 750	41 190	55 230	45 350	54 940	34 000	47 450	39 530	55 170	40 120	55 120	1.003	77 560	0.711							
22	"					21 500	23 500	46 510	54 650			35 000	47 350	40 700	55 660												
23	"	0.20	....	0.744	0.435	21 500	23 750	49 430	54 600	50 580	54 540	42 500	47 900	48 850	55 060	49 710	55 120	1.011	76 620	0.719							
23	"					22 500	23 700	51 720	54 480			44 000	48 000	50 570	55 170												
24	"	0.21	0.63	0.752	0.444	22 500	23 070	50 680	51 960	50 680	51 600	45 000	47 050	50 680	52 980	50 680	52 900	1.025	73 530	0.719							
24	"					22 500	22 750	50 680	51 240			45 000	46 900	50 680	52 820												
25	"	0.21	0.65	0.743	0.434	22 000	22 800	50 690	52 540	50 120	52 300	44 000	45 680	50 690	52 630	51 560	53 130	1.016	74 810	0.710							
25	"					21 500	22 600	49 540	52 070			45 000	46 550	52 420	53 630												
26	"	0.21	0.78	0.744	0.435	22 000	24 940	50 570	57 330	50 570	57 140	43 500	50 000	50 000	57 470	50 290	56 180	0.983	79 310	0.708							
26	"					22 000	24 770	50 570	56 940			44 500	47 750	50 570	54 880												
27	"	0.21	0.84	0.740	0.430	21 500	22 800	50 000	53 020	50 000	53 670	44 500	48 000	51 740	55 810	51 740	56 560	1.054	78 020	0.725							
27	"					21 500	23 360	50 000	54 320			44 500	49 280	51 740	57 300												
28	"	0.21	....	0.741	0.431	22 000	23 100	51 040	53 600	51 040	52 440	46 000	48 030	53 360	55 720	52 780	55 210	1.053	76 850	0.718							
28	"					22 000	22 100	51 040	51 280			45 000	47 150	52 260	54 700												
29	"	0.22	0.58	0.743	0.434	22 500	24 650	51 840	56 800	52 420	56 800	45 000	50 000	51 840	54 150	53 000	55 880	.....	80 230								
29	"					23 000	24 650	53 000	56 800			47 000	50 000	54 160	57 600												
30	"	0.22	0.65	0.747	0.438	21 500	24 330	49 090	55 550	49 090	55 000	43 000	48 900	49 000	55 820	49 660	55 680	1.012	76 290	0.730							
30	"					21 500	23 850	49 090	54 450			44 000	48 650	50 230	55 540												
31	"	0.22	0.77	0.736	0.425	23 000	23 740	54 120	55 860	54 120	55 810	46 500	49 380	54 710	58 090	55 000	57 900	1.037	80 820	0.716							
31	"					23 000	23 700	54 120	55 760			47 000	49 050	55 290	57 710												
32	"	0.22	0.78	0.742	0.432	22 000	22 930	50 930	53 080	51 800	53 270	43 000	46 140	49 770	53 400	50 640	53 880	1.011	75 350	0.715							
32	"					22 750	23 090	52 660	53 450			44 500	46 970	51 500	54 360												
33	"	0.24	0.82	0.742	0.432	20 000	24 870	46 300	57 570	46 880	57 460	38 500	50 000	44 560	57 870	47 460	57 760	.....	81 860								
33	"					20 500	24 770	47 450	57 340			43 500	49 800	50 350	57 640												
34	"	0.25	0.75	0.744	0.435	22 500	25 160	51 720	57 840	51 720	57 700	43 000	50 000	49 430	57 480	50 580	57 470	.....	81 800								
34	"					22 500	25 040	51 740	57 560			45 000	50 000	51 720	57 420												
35	"	0.29	0.81	0.736	0.425	20 000	25 370	51 760	59 690	53 820	59 690	39 000	50 000	45 880	58 720	49 410	58 820	.....	86 100								
35	"					23 750	25 370	55 880	59 690			45 000	50 000	52 940	58 820												
36	"	0.31	0.68	0.732	0.421	22 500	23 060	53 440	54 780	53 440	54 810	44 000	47 240	52 260	56 100	53 150	55 750	1.017	78 430	0.711							
36	"					22 500	23 090	53 440	54 840			45 500	46 650	54 040	55 400												
37	Compression.	0.21	1.03	0.741	0.431	24 000	24 500	55 680	56 840	54 520	57 080	44 500	49 890	51 620	57 880	52 200	57 730	1.011	81 580	0.708							
37	"					23 000	24 500	53 360	57 310			45 500	49 630	52 780	57 580												
38	"	0.31	0.78	0.733	0.422	22 500	24 750	53 320	58 410	53 910	58 300	45 500	49 310	52 720	58 420	53 610	58 580	1.005	80 500	0.728							
38	"					23 000	24 560	54 500	58 200			46 000	49 570	54 500	58 730												
39	"	0.31	....	0.739	0.429	23 500	24 420	54 780	56 920	54 200	56 900	45 500	50 000	53 030	58 270	54 200	58 270	.....	83 390								
39	"					23 000	24 400	53 610	56 880			47 500	50 000	55 360	58 270												
40	"	0.32	0.79	0.741	0.431	23 000	23 800	53 360	55 220	52 780	55 230	43 000	48 230	49 880	55 950	48 720	55 620	1.007	76 980	0.723							
40	"					22 500	23 810	52 200	55 240			41 000	47 650	47 560	55 280												
41	"	0.32	0.85	0.734	0.423	22 500	24 540	53 190	58 010	53 780	57 900	45 000	50 000	53 190	59 100	54 080	58 730	1.015	82 820	0.709							
41	"					23 000	24 440	54 370	57 780			46 500	49 400	54 960	58 390												
42	"	0.32	....	0.760	0.454	24 500	28 210	53 960	62 140	55 070	62 240	.....	.....	.....	.....	.....	.....	.....	92 470								
42	"					25 500	28 300	56 170	62 340																		
43	"	0.33	0.91	0.743	0.434	22 000	25 700	50 690	59 220	51 270	58 960	43 000	51 000	49 540	58 760	51 270	58 760	.....	84 380								
43	"					22 500	25 470	51 840	58 690			46 000	51 000	53 000	58 760												
44	"	0.34	0.60	0.744	0.435	22 250	25 250	51 150	58 050	48 570	57 800	46 500	50 000	53 450	57 470	52 590	57 470	.....	82 760								
44	"					20 000	25 030	45 980	57 540			45 000	50 000	51 720	57 470												
45	"	0.36	0.89	0.736	0.425	23 500	26 000	55 290	61 170	55 880	61 000	46 000	51 000	54 120	60 000	55 890	60 000	.....	88 540								
45	"					24 000	25 850	56 470	60 820			49 000	51 000	57 650	60 000												
46	"	0.37	0.93	0.738	0.428	24 500	25 950	57 240	60 630	57 240	60 690	46 000	.....	53 740	.....	54 030	.....	.....	87 210								
46	"					24 500	26 000	57 240	60 750			46 500	51 000	54 320	59 580												
47	"	0.38	0.89	0.735	0.424	23 000	27 250	54 240	64 270	55 420	64 220	49 000	.....	57 780	.....	.....	.....	.....	93 750								
47	"					24 000	27 210	56 600	64 170																		
48	"	0.39	....	0.740	0.430	23 500	27 550	54 650	64 070	54 650	64 100	49 000	.....	56 980	.....	.....	.....	.....	92 070								
48	"					23 500	27 570	54 650	64 120																		
49	"	0.40	0.87	0.723	0.411	23 500	25 900	57 180	63 020	56 570	62 230	45 500	50 800	55 350	61 800	55 660	61 930	.....	87 290								
49	"					23 000	25 250	55 960	61 440			46 000	51 000	55 960	62 050												
50	"	....	....	0.760	0.454	23 000	27 100	50 660	59 690	50 660	59 580	49 000	.....	53 970	.....	.....	.....	.....	85 680								
50	"					23 000	27 000	50 660	59 470																		

TABLE No. 12.

Shearing Resistance of Round Bars of

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Number.	Kind.	Per cent. of carbon.	Mean diameter. Inch.	Area. Square inch.	Single shear.					
					Of the specimen.		Per square inch.			
					Elastic limit. Pounds.	Ultimate resistance. Pounds.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Mean elastic limit for each bar. Pounds.	Mean ultimate resistance for each bar. Pounds.
51	Rivet	About 0.09	0.757	0.450	18 300	20 500	40 660	45 560		
51	"	"			17 500	20 690	38 890	45 980	39 630	45 440
51	"	"			17 700	20 150	39 330	44 780		
52	"	"	0.757	0.450	15 500	20 250	34 450	45 000		
52	"	"			15 250	20 350	33 890	45 220	34 630	45 260
52	"	"			16 000	20 500	35 560	45 560		
53	"	"	0.759	0.452	14 000	20 650	30 970	45 690		
53	"	"			14 250	20 900	31 530	46 240	31 530	46 020
53	"	"			14 500	20 850	32 080	46 130		
54	"	"	0.757	0.450	14 250	21 050	31 670	46 780		
54	"	"			14 250	21 350	31 670	46 440	31 670	46 910
54	"	"			14 250	20 930	31 670	46 510		
55	"	"	0.755	0.448	13 500	20 000	30 130	44 640		
55	"	"			14 250	20 110	31 810	44 890	31 060	44 780
55	"	"			14 000	20 080	31 250	44 820		
56	"	"	0.757	0.450	16 500	20 200	36 670	44 890		
56	"	"			16 500	20 000	36 670	44 450	35 930	44 600
56	"	"			15 500	20 000	34 450	44 450		
57	"	"	0.756	0.449	15 000	20 600	33 410	45 880		
57	"	"			15 000	20 850	33 410	46 440	33 780	46 440
57	"	"			15 500	21 100	34 520	46 990		
58	"	"	0.755	0.448	15 250	20 490	34 040	45 740		
58	"	"			15 000	20 250	33 480	45 200	33 670	45 190
58	"	"			15 000	20 000	33 480	44 640		
60	"	"	0.756	0.449	17 000	21 600	37 860	48 110		
60	"	"			15 500	20 100	34 520	44 770	35 820	46 100
60	"	"			15 750	20 400	35 080	45 430		
78	"Burden's	.....	0.757	0.450	15 750	18 300	35 000	40 670		
78	Best"				16 750	18 400	37 220	40 890	36 110	40 530
78	wrought-iron.				16 000	17 700	35 560	39 330		
78					16 500	18 550	36 670	41 220		

No. 12.

BARS OF OPEN-HEARTH STEEL.

Mean ultimate resistance for each bar. Pounds.	DOUBLE SHEAR.						Ratio of ultimate resistance per square inch in double to that in single shear.	Ultimate tensile resistance per square inch. Pounds.	Ratio of ultimate resistance per square inch in double shear to that in tension.
	OF THE SPECIMEN.		PER SQUARE INCH.						
	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Mean elastic limit for each bar. Pounds.	Mean ultimate resistance for each bar. Pounds.			
	41 000	41 750	45 560	46 390					
45 440	40 500	42 200	45 000	46 890	43 610	46 460	1.022	63 230	0.735
	36 250	41 500	40 280	46 110					
	33 750	42 700	37 500	47 450					
45 260	35 000	42 700	38 890	47 450	38 240	47 450	1.048	62 670	0.757
	34 500	42 700	38 330	47 450					
	29 750	42 750	32 910	47 290					
46 020	30 500	42 870	33 740	47 420	33 810	47 590	1.034	61 270	0.777
	31 500	43 450	34 850	48 060					
	29 500	43 850	32 780	48 720					
46 910	30 500	43 300	33 890	48 110	33 520	48 390	1.032	62 050	0.780
	30 500	43 500	33 890	48 330					
	29 750	41 760	33 200	46 610					
44 780	30 500	41 730	34 040	46 570	34 040	46 590	1.040	61 800	0.754
	31 250	41 750	34 880	46 600					
	34 000	42 300	37 780	47 060					
44 600	34 500	42 750	38 330	47 500	38 520	47 350	1.062	61 630	0.768
	35 500	42 800	39 450	47 560					
	36 000	44 000	40 090	49 000					
46 440	35 000	43 800	38 980	48 780	39 350	48 890	1.053	62 600	0.781
	35 000	43 900	38 980	48 890					
	31 500	42 250	35 160	47 150					
45 150	33 000	42 550	36 830	47 490	35 720	47 210	1.045	61 870	0.763
	31 500	42 100	35 160	46 990					
	36 000	42 500	40 090	47 330					
46 100	36 500	42 500	40 650	47 330	40 740	47 210	1.024	60 900	0.775
	37 250	42 190	41 480	46 980					
	35 000	37 900	38 890	42 110					
40 530	35 750	37 950	39 720	42 170	39 240	41 960	1.035	51 400	0.816
	35 000	37 450	38 890	41 610					
	35 500	37 750	39 440	41 940					

TABLE No. 13.

Shearing Resistance of Round Bars of Bessemer Steel.

Number.	Per cent. of carbon.	Mean diameter. Inch.	Area. Square inch.	Single shear.			Double shear.			Ratio of ultimate resistance per square inch in double to that in single shear.	Ultimate tensile resistance per square inch. Pounds.	Ratio of ultimate resistance per square inch in double shear to that in tension.
				Specimen.	Per square inch.		Specimen.	Per square inch.				
				Ultimate resistance. Pounds.	Ultimate resistance. Pounds.	Mean ultimate resistance for each bar. Pounds.	Ultimate resistance. Pounds.	Ultimate resistance. Pounds.	Mean ultimate resistance for each bar. Pounds.			
61	0.11	0.751	0.443	21 500	48 530	49 210	44 950	50 740	51 000	1.036	66 270	0.770
61	0.11			21 650	48 870		45 200	51 020				
61	0.11			22 250	50 230		45 400	51 240				
62	0.12	0.751	0.443	23 100	52 140		46 000	51 920				
62	0.12			23 050	52 030	51 470	45 500	51 350	51 470	1.000	65 410	0.787
62	0.12			22 250	50 230		45 300	51 130				
63	0.12	0.749	0.441	21 850	49 550		43 800	49 660				
63	0.12			21 950	49 770	49 740	45 380	51 450	50 940	1.024	65 620	0.776
63	0.12			22 000	49 890		45 500	51 700				
64	0.12	0.752	0.444	21 700	48 900		45 000	50 680				
64	0 12			22 300	50 200	49 470	44 850	50 500	50 540	1.022	64 210	0.788
64	0.12			21 900	49 300		44 800	50 450				
66	0.13	0.758	0.451	22 500	49 890		46 300	51 330				
66	0.13			23 400	51 880	51 000	46 600	51 660	51 510	1.010	65 770	0.783
66	0.13			23 100	51 220		46 500	51 550				
67	0.15	0.747	0.438	21 900	50 000		45 100	51 480				
67	0.15			22 200	50 690	50 500	44 850	51 200	51 260	1.011	66 940	0.766
67	0.15			22 250	50 800		44 800	51 100				
68	0.16	0.753	0.445	22 900	51 460		47 100	52 920				
68	0 16			23 100	51 910	52 280	46 800	52 580	52 840	1.011	68 250	0.774
68	0.16			23 800	53 480		47 200	53 030				
69	0.16	0.749	0.441	22 600	51 250		46 600	52 830				

TABLE No. 13.—*Continued.*

Number.	Per cent. of carbon.	Mean diameter. Inch.	Area. Square inch.	Single shear. Specimen. Ultimate resistance. Pounds.	Single shear. Per square inch. Ultimate resistance. Pounds.	Single shear. Per square inch. Mean ultimate resistance for each bar. Pounds.	Double shear. Specimen. Ultimate resistance. Pounds.	Double shear. Per square inch. Ultimate resistance. Pounds.	Double shear. Per square inch. Mean ultimate resistance for each bar. Pounds.	Ratio of ultimate resistance per square inch in double to that in single shear.	Ultimate tensile resistance per square inch. Pounds.	Ratio of ultimate resistance per square inch in double shear to that in tension.
69	0.16			22 700	51 470	51 280	46 300	52 490	52 550	1.025	68 440	0.768
69	0.16			22 550	51 130		46 150	52 320				
70	0.17	0.747	0.438	23 480	53 610	53 260	46 650	53 250	53 390	1.002	70 140	0.761
70	0.17			23 400	53 420		47 200	53 880				
70	0.17			23 100	52 740		46 450	53 030				
71	0.17	0.748	0.439	22 400	51 020	52 010	47 000	53 530	53 380	1.026	71 880	0.743
71	0.17			23 300	53 080		46 800	53 300				
71	0.17			22 800	51 930		46 800	53 330				
72	0.20	0.752	0.444	22 600	50 990	51 530	47 000	52 930	52 870	1.026	70 510	0.750
72	0.20			23 200	52 250		47 000	52 930				
72	0.20			23 200	52 250		46 850	52 760				
73	0.22	0.757	0.450	24 900	55 330	56 150	50 000	55 550	55 550	.....	76 750	
73	0.22			25 400	56 440		50 000	55 550				
73	0.22			25 500	56 670		50 000	55 550				
74	0.23	0.756	0.449	23 900	53 230	53 270	49 500	55 120	55 440	1.041	72 740	0.762
74	0.23			23 800	53 120		49 900	55 570				
74	0.23			24 000	53 450		49 950	55 620				
75	0.24	0.756	0.449	24 800	55 230	55 450	50 000	55 680	55 600	1.003	76 110	0.731
75	0.24			25 200	56 120		50 000	55 680				
75	0.24			24 700	55 010		49 800	55 460				
76	0.36	0.758	0.451	31 850	70 620	70 190	.....	.....	.....	.....	98 710	
76	0.36			31 870	70 670							
76	0.36			31 250	69 290							
77	0.39	0.762	0.456	30 800	67 540	67 760	.....	.....	.....	.....	95 720	
77	0.39			30 930	67 830							
77	0.39			30 970	67 920							

Number.	METHOD OF SHEAR.	Kind of metal.	Carbon.	Diameter in inch.	Area. Square inch.	SPECIMEN Elastic limit. Pounds.	SPECIMEN
54	All edges sharp. Half circle of shearing block used, as at *G* in the Figure.	Open-Hearth.....	About 0.09	0.756	0.449	14 500	2
				0.757	0.450	14 250	2
				0.757	0.450	14 250	2
				0.757	0.450	14 250	2
55	do do	"	"	0.755	0.448	13 500	2
				0.755	0.448	14 250	2
				0.755	0.448	14 000	2
61	do do	Bessemer.....	0.11	0.751	0.443	13 000	2
				0.751	0.443	13 250	2
				0.751	0.443	14 250	2
				0.748	0.439	14 000	2
76	do do	"	0.36	0.758	0.451	23 000	3
						24 000	3
						24 000	3
78	do do	"Burden's Best" iron	....	0.757	0.450	15 750	1
				0.757	0.450	16 750	1
				0.757	0.450	16 000	1
				0.757	0.450	16 500	1
54	All edges rounded. Half circle of shearing block used, as at *Y* in the Figure.	Open-Hearth.....	About 0.09	0.757	0.450	15 000	2
						15 000	2
55	do do	"	"	0.753	0.445	15 000	2
						14 500	2
61	do do	Bessemer	0.11	0.748	0.439	14 750	2
						16 000	2
76	do do	"	0.36	0.758	0.451	21 000	3
						22 500	3
						23 000	3
78	do do	"Burden's Best" iron	....	0.759	0.452	13 500	2
						13 000	2
54	All edges rounded. Full circle of shearing block used, as at *X* in the Figure.	Open-Hearth.....	About 0.09	0.755	0.448	15 000	2
						15 000	2
55	do do	"	"	0.751	0.443	13 500	2
						14 500	2
61	do do	Bessemer.....	0.11	0.748	0.439	16 500	2
						17 000	2
76	do do	"	0.36	0.758	0.451	23 000	3
						23 500	3
78	.....	"Burden's Best" iron	....	0.759	0.452	15 250	2
						15 500	2
54	All edges rounded. } Span, 2⅛ inches...	Open-Hearth	About 0.09	.....	.....	.....	.
	Full circle used. } " 2¼ "						
55	do " 2⅛ "	"	"	.....	.....	.....	.
	do " 2¼ "						
78	.....	"Burden's Best" iron	....	.....	.....	.....	.

TABLE No. 14.

RESISTANCES OF STEEL WHEN THE EDGES OF THE SHEARING BLOCK ARE SHARP AN

Area. Square inch.	SINGLE SHEAR.						DOU		
	SPECIMEN.		PER SQUARE INCH.				SPECIMEN.		
	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Mean elastic limit.	Mean ultimate resistance.	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Elastic limit. Pounds.
0.449	14 500	20 750	32 290	46 430			31 500	41 770	35 080
0.450	14 250	21 050	31 670	46 780	31 830	46 790	29 500	43 850	32 780
0.450	14 250	21 350	31 670	47 440			30 500	43 300	33 890
0.450	14 250	20 930	31 670	46 510			30 500	43 500	33 890
0.448	13 500	20 000	30 130	44 640			29 750	41 760	33 200
0.448	14 250	20 110	31 810	44 890	31 060	44 780	30 500	41 730	34 040
0.448	14 000	20 080	31 250	44 820			31 250	41 750	34 880
0.443	13 000	21 500	29 350	48 530			33 000	44 950	37 250
0.443	13 250	21 650	29 910	48 870	30 830	49 170	34 500	45 200	38 960
0.443	14 250	22 250	32 170	50 230			35 000	45 400	39 500
0.439	14 000	21 530	31 890	49 040			31 500	43 450	35 560
0.451	23 000	31 850	51 000	70 620					
	24 000	31 870	53 210	70 670	52 470	70 190	.....	.....	.....
	24 000	31 250	53 210	69 290					
0.450	15 750	18 300	35 000	40 670			35 000	37 900	38 890
0.450	16 750	18 400	37 220	40 890	36 110	40 530	35 750	37 950	39 720
0.450	16 000	17 700	35 560	39 330			35 000	37 450	38 890
0.450	16 500	18 550	36 670	41 220			35 500	37 750	39 440
0.450	15 000	24 100	33 330	53 560	33 330	53 950	30 000	47 670	33 330
	15 000	24 450	33 330	54 330			31 000	48 000	34 440
0.445	15 000	24 600	33 710	55 280	33 150	55 340	34 500	47 500	38 770
	14 500	24 650	32 580	55 390			34 500	47 100	38 770
0.439	14 750	25 300	33 600	57 630	35 030	57 780	33 000	49 800	37 590
	16 000	25 430	36 450	57 930			33 000	49 800	37 590
0.451	21 000	32 500	46 770	72 380					
	22 500	39 500	50 110	87 970	49 370	80 550			
	23 000	36 500	51 220	81 290					
0.452	13 500	20 980	29 870	46 420	29 320	46 300	30 500	41 370	33 740
	13 000	20 870	28 760	46 170			32 000	42 200	35 400
0.448	15 000	25 000	33 480	55 800	34 040	55 690	30 500	47 550	34 040
	15 000	24 900	34 600	55 580			32 500	47 670	36 270
0.443	13 500	24 600	30 470	55 530	31 600	55 140	34 500	46 800	38 940
	14 500	24 250	32 730	54 740			34 500	46 500	38 940
0.439	16 500	25 550	37 590	58 200	38 160	58 260	32 500	49 880	37 010
	17 000	25 600	38 720	58 310			33 000	49 900	37 590
0.451	23 000	35 400	51 220	78 840	51 780	78 120			
	23 500	34 750	52 340	77 390					
0.452	15 250	21 680	33 740	47 970	34 020	47 830	35 000	42 600	38 720
	15 500	21 550	34 290	47 680			36 000	42 000	39 820
.....	.....	.....	.....	.....	.....	.....	29 000	45 550	32 370
							28 000	45 200	31 250
.....	.....	.....	.....	.....	.....	.....	31 000	43 850	35 070
							30 000	43 700	33 940
.....	.....	.....	.....	.....	.....	.....	30 000	38 600	33 190

SHARP AND ROUNDED.

	DOUBLE SHEAR.				RATIO OF ULTIMATE RESISTANCE IN			
	PER SQUARE INCH.							
	Elastic limit. Pounds.	Ultimate resistance. Pounds.	Mean elastic limit.	Mean ultimate resistance.	Double to that in single shear.	Single shear with round edges to that with sharp edges. Half circle.	Double shear with round edges to that with sharp edges. Half circle.	Double shear with round edges to that in tension. Half circle.
0	35 080	46 510						
0	32 780	48 720	33 910	47 920	1.024	1.153	1.109	0.857
0	33 890	48 110						
0	33 890	48 330						
0	33 200	46 610						
0	34 040	46 570	34 040	46 590	1.040	1.236	1.141	0.860
0	34 880	46 600						
0	37 250	50 740						
0	38 960	51 020	37 820	50 510	1.027	1.175	1.123	0.856
0	39 500	51 240						
0	35 560	49 040						
.	.....	.....	.....	.....	.....	1.148		
0	38 890	42 110						
0	39 720	42 170	39 240	41 960	1.035	1.142	1.101	0.899
0	38 890	41 610						
0	39 440	41 940						
0	33 330	52 970	33 890	53 150	0.985			
0	34 440	53 330						
0	38 770	53 370	38 770	53 150	0.960			
0	38 770	52 920						
0	37 590	56 720	37 590	56 720	0.982			
0	37 590	56 720						
0	33 740	45 760	34 570	46 220	0.998			
0	35 400	46 680						
0	34 040	53 070	35 160	53 140	0.954			
0	36 270	53 200						
0	38 940	52 820	38 940	52 650	0.955			
0	38 940	52 480						
0	37 010	56 810	37 300	56 820	0.975			
0	37 590	56 830						
0	38 720	47 120	39 270	46 790	0.988			
0	39 820	46 460						
0	32 370	50 840	31 810	50 650				
0	31 250	50 450						
0	35 070	49 600	34 500	49 520				
0	33 940	49 430						
0	33 190	42 700						